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A Prototype Task Network Model to Simulate the Analysis of Narrow Band Sonar Data and the Effects of Automation on Critical Operator Tasks

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Abstract

This is a demonstration project to illustrate the benefits of task network modelling as a means of quantifying future changes to system design or operational concepts prior to the build stage or system implementation. The specific task environment selected for the demonstration is the process of analysing narrow band sonar data to detect and identify sonar targets, which are key tasks in building the Underwater Maritime Picture. Function and critical task analysis of existing sonar analysis practices were conducted to generate appropriate functions and tasks to be modelled. The Integrated Performance Modelling Environment (IPME) software was used to build a task network model, the essential components of which were validated by an experienced Navy sonar subject matter expert. The model was then used to assess the effects of semi-automating the critical process of sanitising ownship and Task Group sonar data from the display, by comparing system performance for baseline (manual) and automated conditions. Results showed a performance increase for the automated of approximately 30% in terms of contacts identified. This performance gain was achieved with no costs to operator workload. The prototype system developed provides core functionality to explore future "what-if" questions with respect to the redesign of sonar systems and their concept of operations.

Résumé

Il s'agit d'un projet de démonstration qui vise à montrer les avantages de la modélisation d'un réseau de tâches comme moyen de quantifier les futurs changements à apporter à la conception de systèmes ou à leurs concepts opérationnels avant la construction ou la mise en œuvre des systèmes. Ce qu'on a retenu comme conditions d'exécution des tâches particulières aux fins de la démonstration, c'est le processus d'analyse des données obtenues par sonar à bande étroite pour la détection et l'identification des cibles sonar, qui regroupe des tâches-clés de l'établissement de la situation maritime sous-marine. L'analyse de tâches critiques et de fonctions a été appliquée aux pratiques d'analyse de données sonar en place pour générer les tâches et les fonctions appropriées à modéliser. Le logiciel d'environnement intégré de modélisation de la performance (IPME) a été utilisé pour la mise au point d'un modèle de réseau de tâches, dont les éléments essentiels ont été validés par un expert chevronné du sonar de la Marine. Le modèle a ensuite servi à l'évaluation des effets de la semi-automatisation du processus critique d'épuration des données sonar de son propre navire et du groupe opérationnel de l'affichage, par une comparaison du rendement des systèmes entre un modèle de référence (manuel) et des conditions automatisées. Les résultats ont fait ressortir, dans le cas des conditions automatisées, une amélioration du rendement d'environ 30 % en ce qui concerne les contacts identifiés. Ce gain de rendement a été réalisé sans accroissement de la charge de travail de l'opérateur. Le prototype élaboré assure les fonctions de base pour explorer les futures questions hypothétiques en ce qui concerne le remaniement des systèmes sonar et leur concept d'opération.

Executive Summary

The task of building the underwater maritime picture depends heavily on the accurate and timely analysis of sonar acoustic data that may be highly uncertain in origin and embedded in background "noise" from a variety of underwater acoustic sources. The task of distinguishing signal from noise and recognising combinations of signals as representative of a particular contact signature falls upon the sonar operator. Previous function and task analyses of passive and active sonar systems have identified the critical tasks performed by operators in identifying contacts of interests. While the time course of many contacts is sufficiently slow, which, in itself, does not produce time stress upon operators, the large volume of acoustic data presents a continuing task of detection and analysis that can be overwhelming for operators to deal with. In particular, acoustic data generated from ownship and adjacent members of a task group may swamp the acoustic analysis system with multiple instances of data that must be sifted through and logged (sanitised), in order to allow a better picture to emerge of the primary acoustic contacts of interest. Thus, there is a continuing interest by researchers in methods to improve the effectiveness of the analysis process by automating certain operator-intensive functions that may require repeated, low-level cognitive analysis. This would free up operators to perform the more complex and critical tasks of analysing contact signatures and classifying sources.

The present project is a demonstration of how automation issues in the analysis of sonar data can be addressed *a priori,* by building a network model that simulates the operator's role. By constructing a baseline model of a generic sonar detection and analysis process and measuring its performance capabilities, we can then ask questions concerning how hypothetical decision-aids or methods of automation may improve upon baseline performance.

A network model of a generic sonar detection task (based largely upon CANTASS) was constructed using information from prior function and task analyses and with input from an experienced Navy sonar instructor. The model comprised a two-operator suite, a processing environment that involved multiple beams of sonar data in the form of simulated frequency-time-intensity displays, with the overall goal that operators identify and log all sonar data that were "present". The model ran for an approximation of a Navy watch, approximately eight hours, during which time approximately 3000 lines of sonar data were generated for analysis. Some of the lines represented acoustic noise of no interest, other lines represent unknown targets, while other lines represented signatures (combinations of lines) of contacts of interest. System performance was measured in terms of the number of contacts logged, the number of times the task group data were sanitised and the number of lines missed. Operator performance was assessed in terms of workload for vision, cognitive, auditory and psychomotor modalities.

To assess the effects of automation on system performance, a semi-automated decision aid was modelled which enabled the operator to more quickly detect, recognise and classify acoustic data coming from ownship or the task group.

A comparison between baseline and automated conditions showed a gain of approximately 30% in the automated condition for the number of lines logged and an eightfold increase in the number of times the data were sanitised. These performance improvements were obtained with no significant effects on operator workload.

Thus, the project has demonstrated that a modelling approach using task network simulation may be used to address a variety of "what-if" questions concerning sonar system re-design and/or

personnel and role re-assignment, and to obtain answers to such questions that are quantitative in nature, and which address operationally relevant system goals. The approach is recommended for identifying critical areas for the selection of decision aids and automated functions in future system re-design, to ensure that the maximum benefit to the operator is obtained in terms of performance effectiveness and workload maintenance.

Sommaire

La tâche d'établir la situation maritime sous-marine dépend fortement de l'analyse précise, en temps opportun, de données acoustiques sonar dont l'origine peut être très incertaine et qui peuvent être intégrées au « bruit » de fond en provenance de diverses sources acoustiques sous-marines. La tâche de distinguer le signal du bruit et de reconnaître des combinaisons de signaux comme éléments représentatifs de la signature particulière d'un contact donné incombe souvent à l'opérateur sonar. Des analyses antérieures des fonctions et des tâches de systèmes sonars passifs et actifs ont permis d'identifier les tâches critiques que l'opérateur exécute dans l'identification des contacts présentant de l'intérêt. Même si de nombreux contacts ont une progression suffisamment lente, ce qui, en soi, ne produit pas de stress lié au temps pour l'opérateur, la grande quantité de données acoustiques occasionne une tâche continue de détection et d'analyse qui peut s'avérer accablante pour l'opérateur. En particulier, les données acoustiques générées par son propre navire et des membres adjacents du groupe opérationnel risquent de submerger le système d'analyse acoustique par de multiples données qu'il faut passer en revue et consigner (épurer) pour permettre d'obtenir une meilleure situation à partir des contacts acoustiques primaires présentant de l'intérêt. Ainsi, les chercheurs portent un intérêt soutenu aux méthodes qui permettraient d'améliorer l'efficacité de l'analyse grâce à l'automatisation de certaines fonctions qui exigent beaucoup de l'opérateur, du fait qu'elles peuvent demander une analyse cognitive de faible niveau à répétition. Cela permettrait de libérer l'opérateur, qui pourrait alors effectuer les tâches plus complexes et critiques d'analyse des signatures des contacts et de classification des sources.

Le présent projet est une démonstration de la façon dont on peut aborder, a priori, les questions d'automatisation dans l'analyse des données sonar, en élaborant un modèle informatique qui simule le rôle de l'opérateur. En mettant au point un modèle de référence d'un processus générique de détection et d'analyse au moyen d'un sonar et en mesurant ses capacités de rendement, nous pouvons alors poser des questions sur la façon dont d'hypothétiques méthodes d'automatisation ou aides à la décision permettraient d'améliorer le rendement de base.

Un modèle en réseau d'une tâche générique de détection sonar (fondé largement sur le système CANTASS) a été mis au point au moyen de l'information obtenue à partir d'analyses antérieures de tâches et de fonctions et avec la contribution d'un instructeur chevronné de la Marine pour l'utilisation du sonar. Le modèle se composait d'une suite pour deux opérateurs, un cadre de traitement qui comporte de multiples faisceaux de données sonar sous la forme d'affichages fréquence-temps-intensité simulés, dans le but général de permettre à l'opérateur d'identifier et de consigner toutes les données sonar qui étaient « présentes ». Le modèle a tourné pour une approximation d'un quart de la Marine, d'une durée d'environ huit heures, période au cours de laquelle environ 3 000 lignes de données sonar ont été générées aux fins d'analyse. Certaines lignes représentaient du bruit acoustique sans intérêt et d'autres lignes, des cibles inconnues, tandis que d'autres lignes représentaient des signatures (combinaisons de lignes) de contacts présentant de l'intérêt. Le rendement du système a été mesuré par le nombre de contacts consignés, le nombre de fois que les données de groupes opérationnels ont été épurées et le nombre de lignes ratées. Le rendement de l'opérateur a été évalué d'après la charge de travail pour les modalités psychomotrices, auditives, cognitives et visuelles.

Afin d'évaluer les effets de l'automatisation sur le rendement du système, une aide à la décision semi-automatisée a été modélisée pour permettre à l'opérateur de détecter, de reconnaître et de

classer plus rapidement les données acoustiques en provenance de son propre navire ou du groupe opérationnel.

Une comparaison entre le modèle de référence et les conditions automatisées a fait ressortir, dans les conditions automatisées, un gain d'environ 30 % en ce qui concerne le nombre de lignes consignées et une multiplication par huit du nombre de fois que les données ont été épurées. Ces améliorations du rendement ont été obtenues sans effet significatif sur la charge de travail de l'opérateur.

Ainsi, le projet a montré qu'il est possible d'aborder la modélisation par la simulation d'un réseau de tâches pour étudier diverses questions hypothétiques concernant le remaniement des systèmes sonar et/ou la réaffectation des effectifs et des rôles, ainsi que pour trouver des réponses à des questions de nature quantitative qui portent sur des objectifs de systèmes pertinents sur le plan opérationnel. C'est une approche qu'il est recommandé d'adopter pour identifier les domaines critiques pour la sélection d'aides à la décision et de fonctions automatisées dans le cadre du futur remaniement des systèmes, si l'on veut s'assurer d'obtenir des retombées maximales pour l'opérateur en ce qui concerne l'efficacité du rendement et le maintien de la charge de travail.

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1. Background

The present project arises from previous work contracted to HSI with the common objective of improving the understanding of human factors issues in the processing of sonar information by human operators. The outcomes of this work serve both the scientific community in its research and development of new sonar concepts, and the operational community in terms of relevance to system design and manning issues. This program has been under the primary direction of DRDC-Toronto as the Scientific Authority with further contribution from DRDC-Atlantic. The program has involved a wide range of studies, as follows:

- An examination of design issues in the human-computer-interface for sonar systems; operator performance in a simulated passive sonar search and classification task (Matthews, Greenley and Webb, 1991)
- A revision to, and upgrade of, a function analysis of CANTASS (Matthews, Webb and Woods, 2001)
- A function analysis of ANS 510 active sonar (Matthews and Webb, 2001)
- A function analysis of TIAPS and review of implications for HCI design (Matthews, Webb and Woods, 2001)

A number of recommendations arising from the latter report have provided the basis for the direction for the current project. These have stemmed from an interest in how emerging ideas and concepts of automated sonar information processing will impact upon the human operators of sonar systems. Such impacts may have implications for system design, function allocation between the system and operators - as well as between operators, manpower levels, operational procedures and training. Of particular interest is how automation will directly change the way operators perform critical tasks of search and identification, and whether system performance can be successfully modelled using a network simulation approach. Such modelling would provide an invaluable tool for assessing *a priori* the impact of different system design alternatives on operator performance and workload. A model of a sonar system would allow, for example, each of the following system concepts to be simulated and the change in system performance from baseline to be quantitatively and qualitatively assessed:

- The impact of increasing the number of sensor beams from 44 to 100
- The maximum number of sensor beams that a single operator can handle before search and/or identification processes degrade
- The additional human-operator capacity that might be achieved through a system that automatically detected and identified known target lines (e.g. equivalent to the operator intensive task of sanitising the passive array)
- The increased capacity that could be created by an automated function that deals with lines that are easy to detect and identify, thereby freeing the operator to focus on more complex detections and identifications
- The impact of a tactical representation of automatically generated sonar data upon the functions and tasks performed by the operator(s) and how the system would perform compared with baseline

Clearly, there is a broad range of practical and useful outcomes from such an analysis and modelling process. The following section deals with the specific goals and objectives of the current project.

2. Goals and Objectives

The overarching and general goal is to develop a demonstration product to show the utility of function analysis, task modelling and network simulation for assessing design alternatives and function automation on operator-system performance in the processing of sonar information. Since function analysis of a number of specific sonar systems has already been accomplished in previous work, the current focus is on task modelling through network simulation.

In agreement with the SA, the following objectives were identified:

1. Develop a generic sonar function flow model and identify potential functions that could be automated.
2. Within the generic model select a critical, core function for more detailed analysis and modelling.
3. Create a baseline task network simulation of the selected function.
4. Evaluate the impact of a specific, automated function on the performance of the system in comparison with the baseline
5. Analyse the impact of such automation on the baseline operator's tasks and mental models.
6. Make recommendations for future work to expand the model to evaluate more complex forms of automation and alternate system designs.

In order to achieve the above, a number of constraints, limitations and assumptions have needed to be made in order to focus the project in a direction that will provide the maximum payoff for the resources available. These factors are addressed in the section four. Before discussing these issues, however, we think it useful to review some basic concepts and definitions.

3. Basic concepts and definitions

3.1 Function analysis

This technique involves the identification of the key functions and their interrelationships that are required to achieve system objectives. Functions represent high-level descriptions of logical units of behaviour of a system that must be performed, rather than describing the engineering or human sub-systems that actually implement the functions. Function analysis consists of a hierarchical analysis and description that starts at the upper levels and progresses to lower levels of decomposition. Typically, the stopping point of the decomposition is at the level of specific task descriptions to be performed by individual operators, hardware or software.

In the function analyses already conducted of sonar systems the primary output has been function descriptions and function flow diagrams. Function flow diagrams represent graphically the sequential functions required to accomplish mission objectives. The flow sequence of the diagrams represents the order in which functions are performed, using AND/OR logic to indicate parallel or serial processes. Each function is numbered in a logical manner to indicate its relationship in the hierarchy. Note that in the work accomplished to date, the SA directed that the function analyses be stopped short of the level of the individual operator tasks.

Function description contain the following components:

1. Name of Function
2. Missions Under Which Function Occurs
3. System Units Which Support Function
4. Super-ordinate Functions
5. Sequential Categorisation of Functions
6. Estimate of Criticality of Function
7. Critical Variables (e.g. own ship speed, own ship manoeuvres, oceanographic conditions)
8. Required Quality of Output for Function
9. Estimate of Probability of Failure to Complete A Function
10. Consequences of Failure to Complete A Function
11. Estimate of Time to Completion
12. Sub-functions Or Tasks
13. Sequencing of Sub-functions or Tasks
14. Allocation of Function to Man, Software or Hardware
15. Interdependency Of Functions

One limitation of function analysis is that it does not show the flow of information nor the critical decisions that need to be made in order to achieve the function. Thus, the analysis needs to be supplemented by an information flow and processing analysis to provide the level of details that will be required to model a system.

3.2 Information flow and processing analysis

This technique is also sometimes call information flow and decision/action diagrams.

This represents a more detailed composition of a function in terms of the specific decisions and task sequences that an operator must perform to achieve the function goals. Typically the analysis is represented as information flow through certain decision and choice points. The flow represents the serial actions that are performed and the consequent routing of information to subsequent tasks based upon the decision outcome.

3.3 Discrete event simulation

This may also be referred to as "task network modelling" and comprises a flow chart approach to representing decisions and actions that are performed over time as an integral part of a system. The specific software employed for the present project (Integrated Performance Modelling Environment-IPME) uses an underlying discrete event Monte-Carlo simulation engine to build a computer model and database of the task environment. A computer model of the process allows answers to "what if" questions. What if we change the way humans work with the system? What if we change the tasks done by humans and software? What if we rearrange the process?

The key functions of IPME that will be used in this project include:

Environment Model: The analyst can model environmental factors or what behavioural scientists refer to as performance shaping factors. These include environmental variables such as temperature, humidity, time of day, etc.

Operator Characteristics: Operator Traits and States may be simulated. Traits are variables such as mental ability, susceptibility to motion sickness, time since trained, etc. States are variables such as fatigue, hunger, etc. The Operator State is dynamically updated during a simulation. Therefore, each operator in the simulation can have unique characteristics.

Performance Shaping Functions: Performance Shaping Functions (PSFs) are user-defined functions which dynamically modify individual operator task "Time to Perform" and "Probability of Failure" values. PSFs define how performance shaping factors (environment variables or operator characteristics) affect operator performance. PSFs are linked to individual tasks through a task taxonomy allowing one PSF function to be dynamically applied to any similar task in a model. Since PSFs can use operator states as expression variables, simulations can be built that have two operators performing the same task type with different, and therefore more realistic, "Time to Perform" and "Probability of Failure" values.

Visual, auditory, cognitive, psychomotor (VACP) and W/Index: the IPME model allows for estimates of operator loadings in these four areas and also calculates an overall workload index. VACP is an attentional demand algorithm based upon the task loading for an operator within the four separate channels and estimates the demands on human processing resources. To achieve a VACP rating, each operator task is rated with respect to the weighted task demand that appears appropriate for the specific task requirements for each of the four independent channels. Scales to assist the generation of these ratings were developed originally for an LHX mission function analysis performed by Aldrich and others (1984), for the US Army Research Institute. The scales provide a subjective rating for various levels of attentional demand. Additional work was later published by Bierbaum, Szabo, and Aldrich (1987) and provided enhanced descriptors and interval scale values.

The following table shows the rating scales for exemplar tasks for each of the four dimensions.

Ordinal rating (W/Index)	Interval rating (VACP)	Descriptor
VISUAL		
1	1	Register/Detect (Detect Occurrence of Image)
2	3.7	Discriminate (Detect Visual Difference)
3	4	Inspect/Check (Discrete Inspection/Static Condition)
4	5	Locate/Align (Selective Orientation)
5	5.1	Track/Follow (Maintain Orientation)
6	5.9	Read (Symbol)
7	7	Scan/Search/Monitor (Continuous/Serial Inspection, Multiple Conditions)
AUDITORY		
1	1	Detect/Register Sound (Detect Occurrence of Sound)
2	2	Orient to Sound (General Orientation/Attention)
3	4.2	Orient to Sound (Selective Orientation/Attention)
4	4.3	Verify Auditory Feedback (Detect Occurrence of Anticipated Sound)
5	4.9	Interpret Semantic Content (Speech)
6	6.6	Discriminate Sound Characteristics (Detect Auditory Differences)
7	7.0	Interpret Sound Patterns
COGNITIVE		
1	1.0	Automatic (Simple Association)
2	1.2	Alternative Selection
3	3.7	Sign/Signal Recognition
4	4.6	Evaluation/Judgment (Consider single Aspect)
5	5.3	Encoding/Decoding, Recall
6	6.8	Evaluation/Judgment (Consider Several Aspects)
7	7.0	Estimation, Calculation, Conversion
PSYCHOMOTOR		
1	1.0	Speech
2	2.2	Discrete Actuation (Button, Toggle, Trigger)
3	2.6	Continuous Adjustive (Flight Control, Sensor Control)
4	4.6	Manipulative
5	5.8	Discrete Adjustive (Rotary, Vertical Thumbwheel, Lever position)
6	6.5	Symbolic Production (Writing)
7	7	Serial Discrete Manipulation (Keyboard Entries)

Table 1: IPME VACP rating scales and descriptors

The Workload Index, or W/Index, algorithm is based on the Hybrid W/Index algorithms developed by Sarno and Wickens (1992) and measures the resource demand imposed upon the operator within resource channels. W/Index decomposes a task into a set of channels and establishes weights representing the amount of demand required for a task in each channel. Unlike the traditional models, W/Index also accommodates interference between channels.

The W/Index model makes two calculations. The within channel contribution sums the demand contributions in each channel as if there was no interference. The between channel contribution looks at each pair-wise combination of active tasks, takes the within-channel contribution for each task, and scales the values using the values in a conflict matrix.

The channels used for this model include visual perception, auditory perception, verbal cognition, spatial cognition, manual response and speech response. Ratings are based on ordinal categories (integers from 1 to 7).

With respect to the Cognitive component of the scale it should be noted that there is no specific rating for tasks that may have a high memory component, for example, when an operator returns to a display that has been updated since it was last inspected (which could be as much as ten minutes) and needs to remember what lines were previously there, what contacts they were associated with and what is new information. Even with “cheat sheets” or other notations that an operator might make to assist in reducing the memory load for this task, there would still appear to be a high memory demand that is not reflected in the ratings that are available.

The specific VACP values chosen for each task will be described later in this report as we go through a full description of the model.

4. Constraints, Limitations and Assumptions

4.1 The baseline sonar system

A baseline system is one that represents and models in detail the essential components and tasks required to analyse sonar data, against which any changes in system design, procedures or manning levels may be directly compared. Clearly there are a number of existing sonar systems that could be candidates for exact modelling, whether the focus is active, passive or sonobuoy sensors. In considering what sort of system to be modelled, it should be remembered that the purpose of creating a baseline system is to make it as generic as possible, but sufficiently grounded in existing system reality to make it valid for comparison purposes. Therefore, there is a need to identify the functions and attributes that are more or less common to all systems, whatever the underlying sensor configuration or signal processing characteristics. These functions include:

- Analysis of the mission
- The configuration of the system to appropriate underwater conditions and potential contacts of interest
- The assessment of the system
- The display of processed sonar data
- The creation of the tactical picture- which requires:
  - The search by an operator of such data for sonar contacts of interest
  - The interpretation and the analysis of the data to allow formal identification, classification and determination of contact range, speed and track.
  - The assessment of threats
- The management of the underwater tactical picture

Subsidiary tasks to support these functions may include target localisation, motion analysis and the correlation of information across sensor systems and other platforms. These primary functions and their relationships are shown in the function flow diagram in Figure 1, which has been derived from the previous function analyses performed on ANS 510, CANTASS and TIAPS. Detailed descriptions of these functions can be found in the relevant reports cited above.

Figure 1: Function flow diagram of generic sonar system

4.2 Automation possibilities

Across the broad range of generic system functions, a number of automation concepts are possible or have been conceived by research scientists. To provide a context for the present work, a small-scale survey was initially conducted of ongoing automation projects at DRDC Toronto and Atlantic. The information was compiled from interviews with Defence Scientists at each of the above as well as from reports and publications that were made available. The following table shows a summary of the information obtained.

Sonar function	Automation opportunities	DRDC Projects
1. Analyse mission		
2. Configure system		
2.1. Active sonar	Decision aids for setting active transmission parameters	
2.2. Passive sonar	Decision aids for array configuration	
2.3. SPS	Decision aids for buoy deployment	
Generic	Aids for developing underwater model	
3. Assess system		
Generic	Operator feedback on sensor performance to fine tune sensors	
	Operator feedback on model performance to fine tune model	
4.2. Detect contacts		
Generic-computer aided detection	Decision aids for where to look for possible contacts	G.H.
	Decision aids for what to look for	G.H.
	Improving signal-noise ratio by decluttering	
	Operator load reduction by dynamically allocating between system and operator	I.F. R.K.
Lofargrams	Auto line detection	G.H., S.McF.
	Neural networks for classifying transient sounds	I.F.
Active sonar	Auto feature detection to aid declutter	W.R.
	Auto echo detection	G.H.
Passive sonar	Auto detection of signals (reduce false alarms)	W.R.
	Aids to de-clutter the obvious	W.R.
	Low level signal followers	G.H.
SPS	Enhancing the buoy by buoy analysis	J.M.
	Smart output summary from all buoys	J.M.
Sensor integration: correlation of info across sensor /radar systems, platforms	TIAPS COMDAT	G.H. B.M.
	NUW TDP	W.R., B.M.
	Fusing active/passive data	G.H.

Table 2: Opportunities for automation, cross-referenced to generic sonar functions
(continued on following page)

Sonar function	Automation opportunities	DRDC Projects
4.3.1 Identify contact		
Generic	Decision aids for target ID-database of target signatures	
Passive	Decision aids for target ID from line pattern	G.H., B.McA.
	Decision aids for ID from transients (e.g. subs)	I.F.
Active	Decision aids for target ID	
Mines	Side scan radar for auto detection	R.K.
	Human-machine co-operative detection	R.K.
Torpedo	Auto detection	
4.3.2 Locate target	Auto location from airborne sonobuoy signal and multistatics	IMPACT
	Auto representation of spatial uncertainty (target probability location)	G.H.
4.3.3 Determine speed	Auto calculation for TMA	Passive Localisation Assistant
4. Create tactical picture		
Correlation of information	MSDF integration of info across systems (NUW)	W.R., B.McA., B.M.
Picture representation	Integrated tactical and sonar plot	COMDAT
Visualisation of oceanography	NUW	
Information management	Reduce info load on operators/improve information integration across systems	SIMS
5. Manage tactical picture	Auto track followers	S.McF.
	Auto track deletion	

Table 2: Opportunities for automation, cross-referenced to generic sonar functions
(B.M.- Brian Martin, B.McA-Bruce McArthur, G.H.-Gavin Hemphill, J.M.- Joe Maksym, I.F-Ian Fraser, W.R. Bill Roger, S.McF-Sharon McFadden, R.K- Ron Kessel, SIMS – Sonar Information Management System, COMDAT-Command Decision Aid Technology)

Clearly, the scope of the present project requires that some narrowing of automation possibilities be undertaken, since the complete modelling of all sonar functions and associated automation concepts would be a formidable and labour intensive task. Therefore, in consultation with the SA, a decision was made to concentrate on the core and critical functions of sonar signal detection and contact identification.

4.3 Identification of critical and core tasks

The key central component of any generic sonar system is the requirement that all sonar data that are sensed and displayed by the system are accounted for. This means that all lines on a typical sonar display must be detected by the operator, interrogated, analysed, identified and logged. The conduct of such tasks is a pre-requisite for subsequent functions that are important to building the underwater picture, and which typically include contact classification, contact range, speed and track estimation and threat assessment. Thus it follows that none of these tactically critical functions can be successfully executed if the prior tasks are performed inadequately.

Thus, the baseline system to be modelled should include the tasks of detecting sonar data of interest from noise and the process of analysis that results in a classification into the formal categories of: unknown, suspect, friend, neutral and hostile.

While this process represents a core component in any sonar processing system, it should be noted that it represents just a small sub-set of the entire range of sonar analysis that would normally be conducted in an operational context, as exemplified in the following diagram, which has been provided courtesy of Navy Sea Training. Note that the functions selected for modelling fall within the area indicated by the grey box and within this the focus will be largely on narrow band (NB) analysis.

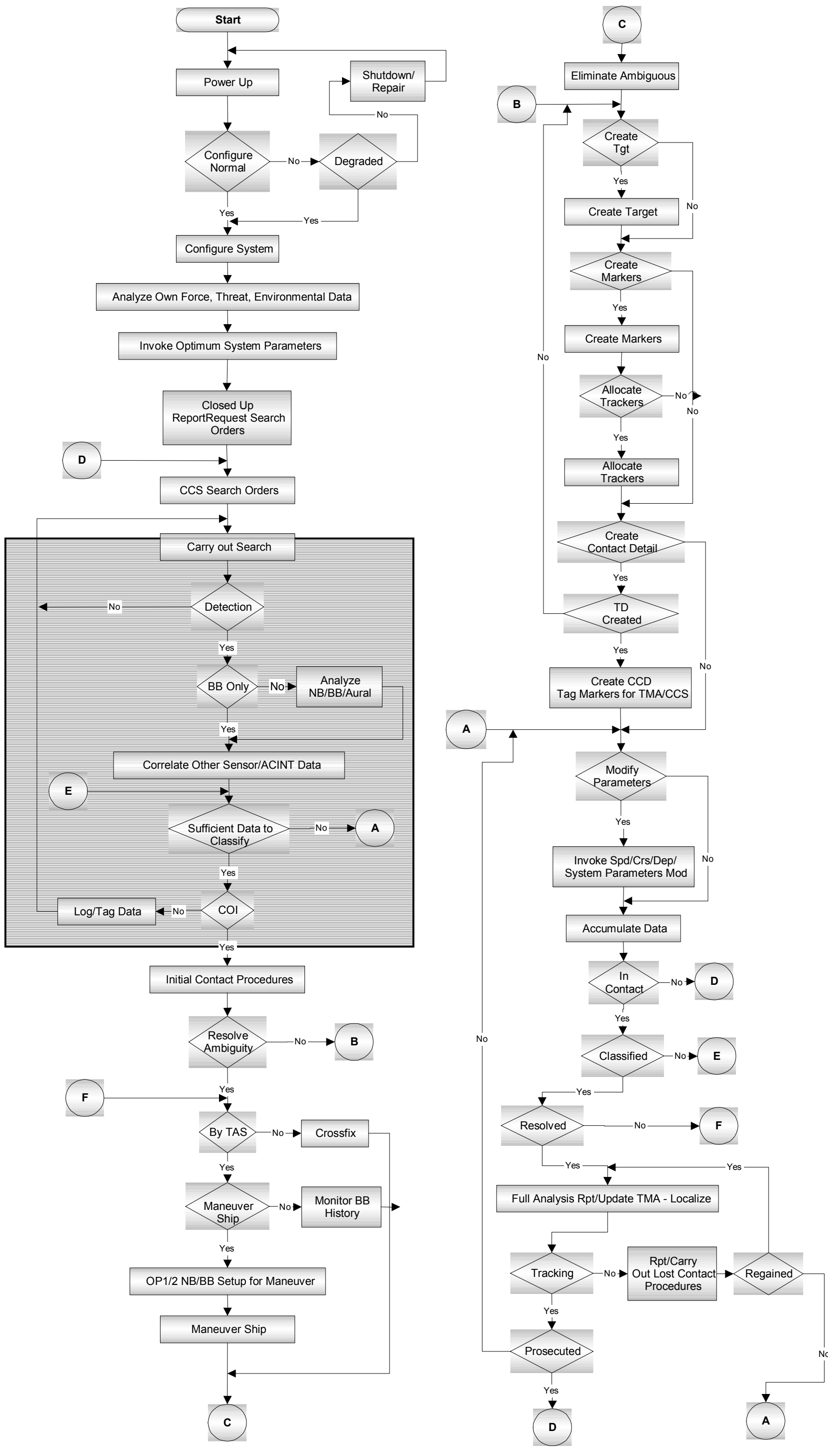

Figure 2: Detailed task flow of the search-to-analyse process that reflects current Canadian Navy Concept of Operations.

4.4 Operational environment

The environment comprises a deep-water operation in the context of a typical Canadian Navy Task Group (TG) comprising one mission essential unit, a destroyer, three frigates and an MPA. The TG is moving at a speed of 12 knots. This is considered to be a broadly representative configuration.

The start of the modelled process assumes that a watch handover has taken place and the operators have received intelligence and briefings concerning potential contacts and threats. The sensor system has been deployed and has been transmitting data over previous watches.

4.5 System Hardware

In order to approximate the realities of existing sonar systems the hardware constraints have been set as follows:

- Two high-resolution monitors
- Processed, narrow band, sonar data are represented on 44 beams (although in principle this number may be readily manipulated). A beam is considered to be a cone of reception that projects on a specific bearing from the sensor system.[1]
- Data are represented as frequency information over time. There are three display resolutions per monitor which approximate single, triple beam and search summary formats of CANTASS.
- Broadband information is not displayed
- Aural presentation of sonar data is available to operators
- The baseline system does not employ auto-trackers, or operator initiated tracks.

4.6 Number of operators

This is a system parameter that could be systematically manipulated if desired. As a starting point we have assumed a manning level of two operators. who each perform all of the tasks in parallel. This would seem to be a sensible starting point for the model based upon existing operational circumstances and what is known about the associated typical operator workload. Unlike existing systems, we have chosen not to add an additional "operator" to assist in the task of classification. Although, the baseline model could be readily modified to accommodate any number of personnel who perform any of the core operations.

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[1] While the concept in the generic model is that of a beam, in fact this could represent any type of sensor configuration (e.g. multiple sonabuoys) which will require a multiple representations that will exceed the capacity of a single screen, and therefore require a multi-screen format. Thus, when the term beam is used throughout the report, it should be interpreted to represent any single sonar display that represents a depiction of one subset of the total sonar data.

4.7 The underwater model and sonar contacts

The detailed simulation of the complexity of the underwater environment and its interactions with the wide range of sonar data that are created by mechanical and non-mechanical sources is beyond the scope of a baseline model. Instead, we start with the assumption that there are a number of sonar sources that will have a variety of sound frequency components that arrive at the sensor and are presented on a display, or can be heard through headphones or speakers. These sonar data may come from biological or mechanical sources whose frequency characteristics may be known or unknown and are associated with a certain probability of being detected from random, background noise. Note that there is no attempt to represent or simulate this noise in itself. Thus the sonar database comprises a number of signal representations that correspond to sources that, when processed by the operators, should result in identifications of non-mechanical, unknown, suspect, or known. The particular frequency characteristics and the numbers and types of signal sources are described later in this report in the section that provides a full description of the model.

4.7.1 Target spatial dynamics

Since the baseline model does not include tasks of localisation or target motion analysis, nor can include the complexities of TG movement through the ocean, sonar sources are represented on a single beam only. Further, we do not represent whether the sonar data arrive from bottom bounce, direct path or convergence zone. While this may be unrealistic of many operational conditions it does faithfully represent the task of detecting and identifying sonar contacts that are represented on a single beam.

The model function assigns lines of data randomly to the 44 beams.

4.7.2 Target temporal dynamics

A further constraint on the contact sources targets is that their associated data are defined as having a finite, temporal lifespan that will enter into the simulated underwater environment at varying points in time. In this way, the information available to the operator will change over time and, if the data are not processed before they expire, then contacts will be missed or misclassified.

We have used the following logic to determine the time each line will be available to be processed by the operators:

A variable named "life" is assigned a random value between 200 and 600 seconds using the function:

life = randInt(200, 600);

if clock<300 then (life += (300 - clock);

expiration[tag] = clock + life;

A unique array variable named "expiration[tag]" is assigned to each line. The value of this variable indicates the exact clock time when the line will scroll off the screen. The value of expiration[tag] is calculated by adding the current clock time (system clock) plus the random value of the variable named "life".

An exception occurs during the first 300 seconds of the simulation when the array is being populated with lines. During this time the Operators are not permitted to carry out any tasks. A special calculation is required to prevent lines from being missed before the Operators are permitted to start searching. If the current clock time is less than 300 seconds, the value of "life" is

calculated by adding the value of "life" plus the difference between 300 seconds and the current clock time (i.e. 300 - clock).

4.7.3 Target range prediction

Under normal operational circumstances the operator will calculate the range at which lines of specific frequencies can be expected to be detected. This will depend upon the contacts that can be expected and that are provided in the Threat Assessment Pack as well as the underwater conditions that will influence propagation. For the purposes of this initial baseline model, we have assumed that this process has been done and that all lines that enter into the model represent lines that exceed the range prediction criteria. If necessary, this is a process that could be modelled in the future.

4.7.4 Sonar data types

We have modelled four characteristics of sonar data as follows:

- Source is a true target
- Source is noise
- Sonar data may require the operator to wait for additional screen updates
- Sonar data scroll off the display before the operator has time to make an identification.

The probability with which each of these was generated within the IPME model and the function logic is shown in the following table.

Signal Event Type	Probability	Case	Description
Real Sonar Signal	p= 0.22	Line Confirmed	Sonar signal has scrolled up screen far enough to indicate a line of interest.
		Confirmed Line Continues	A line of interest has begun to scroll up the screen.
Signal with insufficient data	p= 0.33	Unconfirmed Line Begins	A line has started at the bottom of the screen but has not been on screen enough cycles to confirm it is a line of interest.
		Unconfirmed Transient Begins	A transient has started at the bottom of the screen but has not been on screen enough cycles to confirm it is a transient.
		Unconfirmed Noise Begins	A noise line has started at the bottom of the screen but has not been on screen enough cycles to confirm it is just noise.
Noise	p= 0.22	Noise Confirmed	A noise line has scrolled up the screen far enough for the operator to confirm it is just noise.
		Transient Confirmed	A transient has scrolled up the screen far enough for the operator to confirm it is a transient.
Line scrolls off screen	p= 0.22	Confirmed Line Scrolls Off Screen	A line of interest has started to scroll off the top of the screen. The Operator is unable to distinguish the line from noise.
		Noise/Transient Scrolls Off Screen	A noise line has started to scroll off the top of the screen. The Operator is unable to determine if this is signal or noise.

Table 3: Characteristics of sonar data

4.7.5 Target identification characteristics

This task could be modelled in a variety of methods depending on the level of complexity of the human processes that are to be simulated. To simplify the task we have assumed that there are 20 lines on each beam (associated with a target) that have to be present before the target can be identified. If such lines are not present, then the target is either missed or classified as unknown. Because the task of generating 20 frequencies at each beam requires a large amount of IPME code and CPU processing time, we have simulated this process by only using half as many lines per target per beam, but requiring that there are two lines at each frequency that have to be present for the target to be identified. This arrangement generates identification times that are consistent with the wide range of actual ID latencies that occur under operational conditions.

Again, it should be noted that this function could be simply modified in future versions of the model to generate different temporal characteristics to the identification process.

4.7.6 Ownship/TG data

These data result from the sensor array picking up on a continuous basis acoustic data generated by noise sources on the ship towing the array and other members of the TG. These data are ever present and can at times "overwhelm" the display, in the words of a sonar SME. As a result of information received during the validation process (see section 8), and after discussions with the Scientific Authority, it was decided not to populate the system with TG data, but instead model the operator processes in dealing with "virtual data" directly. For the purposes of expediency and practicality two values were chosen for the numbers of lines per ship, representing a low and moderately high TG "noise". For the low condition, the operator would be required to "process" 25 lines per ship, each represented on five different beams for each of the five ship TG for a total of 625 lines for the entire TG. For the high condition there were 100 lines per ship, for a total of 2500 TG wide. It should be noted that such values could be simply changed in the model depending upon future user needs.

4.8 The operator model

There are two functionally separate elements of the operator model – the basic search and analysis for contacts of interest and the sanitisation of the array of the known lines arising from the TG. One operator is assigned the task of search and analysis only, while the second operator is required to sanitise the array on a regular basis, and only when finished, take on the task of search and analysis to supplement the role of operator one.

The standard model of operation assumes that each operator searches through the beams in triple beam mode to detect sonar data of interest, identify the source and log the relevant data for each line detected. One operator sequentially searches up the beams from 1-44 and the other from 44-1. When sonar data are encountered by an operator, the search process is halted and the identification/classification process is started by that operator on a single beam. The operator resumes the search at the interrupted point, once the classification task is completed. Thus, the tasks of search and classification cannot be performed in parallel by a single operator and require time-sharing.

When one operator interrupts the search to analyse data, the other operator continues to search until, or if, the conditions arise that require this operator also to engage in the analysis process that results in classification.

At the start of the watch (i.e. when the simulation commences) one operator will "sanitise the array" while the other operator searches. Once this process is complete, the operator will also search for contacts. The sanitisation process will recur during the watch, as part of the ongoing search, as ownship and TG lines migrate across different beams due to the changes in relative positions of the sensors and the various ships.

5. Core functions and the model of information flow

The selection of core functions for modelling is based upon previous function and task analyses and discussions with a Navy sonar SME. The functions were chosen because they are time consuming, repetitive, rely on human judgment and memory, are possibly prone to error, and if improperly or inadequately performed can lead to identification errors. These functions form the critical, central core of the larger task of building the underwater tactical picture. If they are not performed with accuracy and in a timely manner, the ensuing tactical picture will be at best incomplete or could be outdated or even wrong. This in turn would impact upon the assessments of threats and have implications for threat response and weapons deployment. As an example of the criticality of this process, HSI has witnessed underwater identification errors in a practised Navy team undergoing training, whereby an improperly analysed underwater contact led to an inappropriate torpedo launch that compromised the ownship location to the simulated enemy.

The core functions that we have identified are: sanitizing the array, detection and analysis of lines and data logging. Within the constraints of the present contract and under the direction provided by the Scientific Authority, this report focuses on the first two of these only. The principle elements that comprise these core functions are shown in the following flow diagrams.

The first diagram describes the information flow, functions and decisions relating to the task of sanitising the array. The second describes the search and identification process. Square boxes represent tasks: input usually enters from the top, but sometimes may be displayed as entering from the side for clarity. Output always exits from the bottom. Diamond shaped boxes represent decision points. Information always enters from the top. A flow of information from "No" decision exits from either side, and a "Yes" decision always from the bottom apex.

5.1 Sanitising the array

We have adopted the term used by the Navy to describe the process by which ownship and TG lines are accounted for in the display(s) of sonar data. This process can be considered to be a necessary function that has to be performed for any type of sonar system that will be sensitive to the reception of ownship and TG propagations and hence populates the resulting displays with data. Under normal operational conditions there can be as many as 1000 lines emanating from the TG, that is, about 200 per ship and each line could be represented on several beams. These lines correspond to multiple discrete noise sources on each ship, each of which generates a fundamental frequency and several related harmonics. In such cases, a single operator could spend almost an entire watch on the sanitisation process alone. The presence of such data on the sonar displays has three major implications for operator performance. First, they will increase search time for other sonar lines of interest on any single display. Second, they make the task of identification and classification of other contacts held on the same display more difficult. (Indeed, an enemy tactic may be to take up a position in which ownship data may be masked or obscured by ownship or TG data.) Third, they add considerable, overall workload because the process is more or less continuous (see below).

Sanitising the array is essentially a top-down process by which the operator uses information that is available from the log, Threat Assessment Pack or watch handover messages to direct the search for lines associated with ownship and TG. As the operator finds the required lines on the

appropriate beams, the operator enters the required information into the log. All lines associated with ownship and TG must be accounted for and entered into the log.

Since the relationship between the array and ownship and TG will change during the course of a watch, the beams on which the associated data are received will also change; also changes in a contact's speed and the electro-mechanical systems in operation will change the frequencies sensed and displayed. Thus, the requirement for sanitisation will recur throughout the watch. However, in contrast to the initial process by which all ownship and TG data are accounted for on all beams, the subsequent tasks of sanitisation that occur during the standard search, take place on a beam by beam basis (as each beam is scrutinised sequentially as part of the standard search). Therefore, these subsequent acts of sanitisation become embedded within the overall search and detect functions performed by the operators. For present purposes, we have required the operator to re-sanitise the array after a delay of 10 minutes following the previous sanitisation.

The information flow diagram for this is shown on the following page. The specific tasks and decisions represented in this diagram will now be described and the initial assumptions concerning their performance dynamics are outlined.

Review Threat Assessment Pack (TAP)- ownship lines: The TAP is a source of accumulated information concerning known sonar data of interest. It could be expected to contain frequency characteristics and areas of probability of known contacts as well information about ownship and TG sonar data. The operator reviews the TAP to find information concerning which beams to look on and which frequencies to look for concerning ownship lines.

Sub-tasks:

- Locate TAP
- Scan TAP

Select beam: based upon the information obtained from the TAP, the operator will select the triple beam set that is likely to contain the lines of interest.

Sub-tasks:

- Menu-select to bring up beam on display

Search beam for ownship/TG: The operator scans the triple beam set for evidence of sonar data at the frequency of interest. Performance here will depend upon the number of lines present on the beam and the detectability of the individual lines.

Are all ownship data accounted for on this beam? This decision is the outcome of the search. If the answer is "no", the operator iterates through the search process. If there is evidence, then the operator continues with the next task.

Sub-tasks:

- Scan each beam
- Detect signal
- Remember lines associated with TG member of interest

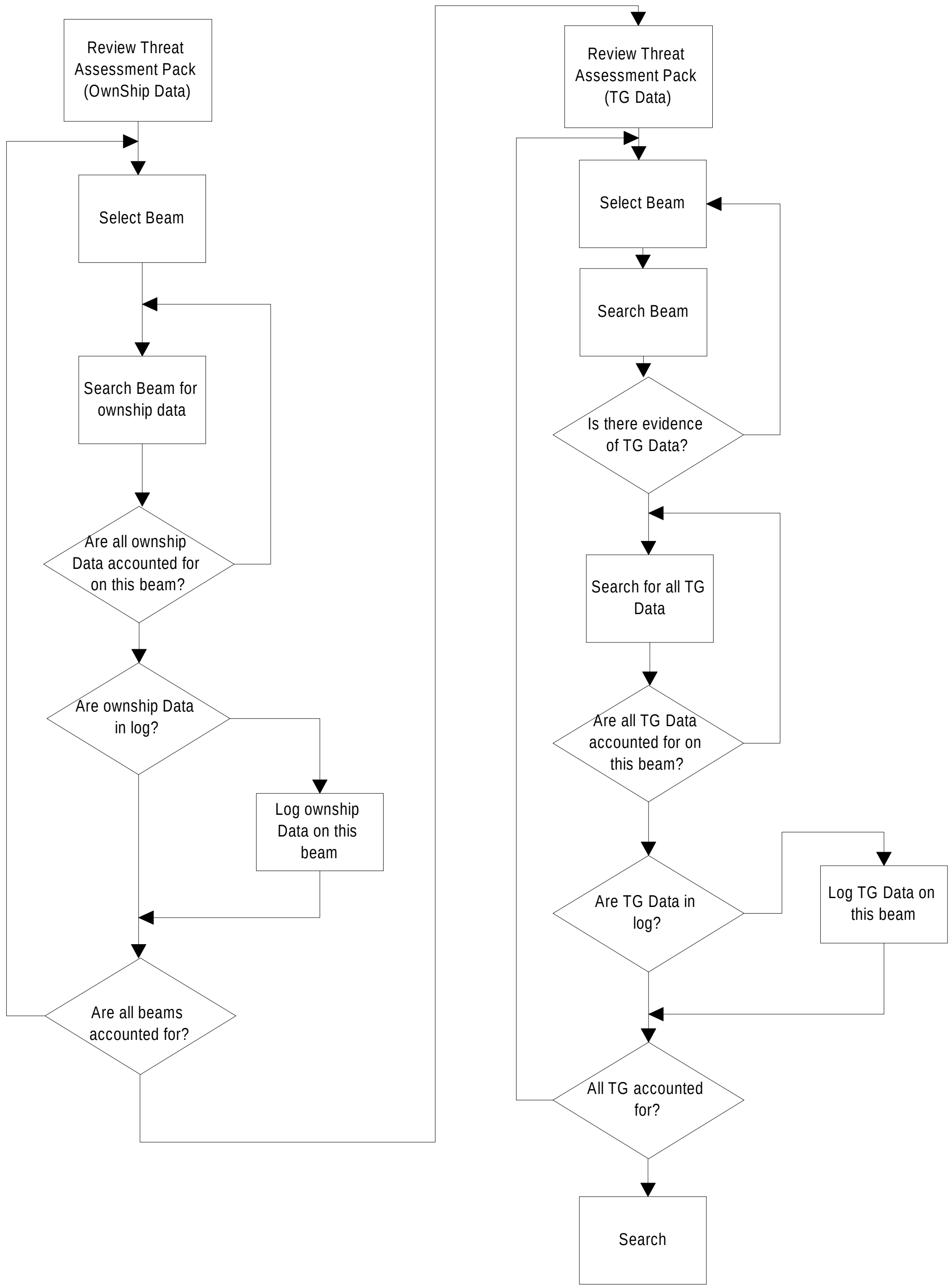

Figure 3: Information flow diagram to illustrate the sanitisation process

Are ownship lines in log? Prior to entering the lines in the log, the operator checks to see if they are already there. If they are the operator proceeds to the next step, if not the operator enters the lines.

Sub-task:

Scan through pages of log

Detect appropriate log entry

Log ownship lines on this beam: The operator logs a number of pieces of information concerning the sensor configuration, environmental and oceanographic conditions as well as the beam number and frequencies associated with ownship. The first set of information concerning context may take up to 30 seconds to log, onto which must be added the time for each line frequency entry.

Are all beams accounted for? If the TAP and experience indicate that ownship lines are likely to be held on adjacent beams, the operator must check this out by calling up the display for those beams, if not already part of the current triple beam set. If all beams are accounted for, the operator proceeds to the sanitisation process for the TG lines. If not, the operator reverts back to selecting another beam for inspection.

Sub-task

Menu select other beams

The process for sanitising the array for TG lines is essentially the same as that for ownship lines, except that it must be repeated for each of the four remaining members of the TG.

At the completion of this process all lines associated with the TG will have been accounted for and logged and the operator now proceeds to the last beam (#43) to commence the search for other sonar data by scanning the beams in the reveres order from the other Operator.

5.2 The search and identification process

The tasks and decisions are described below and are illustrated in the diagram on the next page..

Select triple beam set: The operator selects the initial triple beam set to be examined. As mentioned earlier, search is conducted serially through the beams, with one operator starting at beam 1 and the other at beam 44.

Search triple beam set: the operator searches through each of the beams in the set for acoustic data in the form of pixels that are brighter than the background noise. The operator will need to wait for at least three screen updates for sufficient visual evidence to accumulate.

Sub-tasks:

Menu-select to bring up beam on display

Is there evidence of a signal? The operator decides whether the accumulated information provides evidence of a sonar signal source. If there is no evidence, the operator goes back and selects the next triple beam set.

Sub tasks

Scan each beam

Detect signal

Is it real or statistical noise? Based upon experience, the operator decides whether the signal is being produced by "random" statistical noise, or is evidence of a real sonar contact. If it is deemed

to be noise, the operator continues the search for a signal. If it is real, the operator goes to the next step of examining the data more closely.

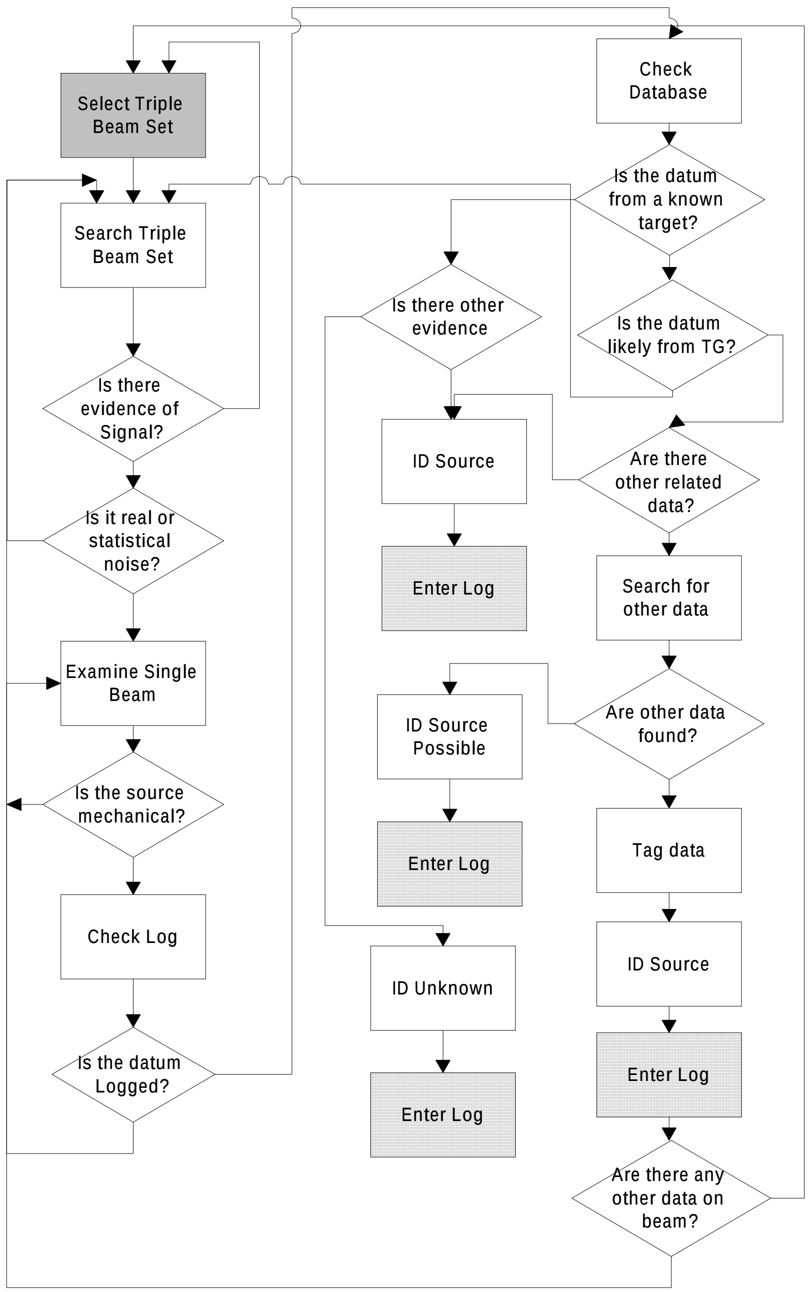

Figure 4: Information flow diagram to illustrate the basic search and identify process

Examine single beam: The operator changes from triple beam to single beam mode in order to examine the data more precisely.

Sub tasks:

Menu select:

Detect signal:

Is the source mechanical? Based upon experience, the operator decides if the source of the noise is mechanical or non-mechanical (e.g. biological). If the latter, then the operator resumes the search. If the noise is thought to be mechanical in origin the operator proceeds to the next task.

Check the log: the operator checks the log to see if this line has already been entered, i.e. accounted for.

Sub task:

Scan through pages of log

Is the datum logged? If the datum associated with this line is already logged, the operator checks the log information and if the entry appears to be valid for the current line, returns to the search process. If there is no entry, or if it appears that the line could be part of a different sonar signature, the operator continues with the next step.

Check database: The database refers to any source of information that may contain data of relevance on the current line. It could be part of the TAP, notes left by the previous shift, a communication, another operator etc. In any event, some time will be spent while the operator determines whether there is any useful information available for this line.

Sub tasks (potential tasks only – not all may be done)

Check TAP

Check paper messages

Check handover log

Is the line(datum) from a known target? Based upon the information that is found, the operator determines whether the source is likely to be known or not. If it is not a known source the operator must determine if there is any other evidence that could assist in providing more information on this line. If it is a known source, the operator will then look for other lines that are known to be associated with this source (information flow skips the following three steps)

Is there other evidence? The operator checks all potential sources that could provide information on the line. If there is not, then the operator proceeds to identify the source as unknown. If there is other evidence, the operator proceeds to identify the probable source.

Sub tasks:

Listen to acoustic data

Check information from: other sonar systems, other platforms, helo, MPA, GCCS

ID unknown: in the absence of any information on the line, the operator identifies it as "Unknown"

Enter Log: The operator enters all relevant information on the line into the log and assigns the formal ID of unknown. The operator then resumes the search.

Are there other related lines? If information held on the line suggests that it is associated with a source which does not generate any other lines, and the line is unique to this source, then the operator can formally identify the source (friend, hostile, neutral). If the information held on this

line suggests that it is associated with a source that generates other lines, then the operator needs to search for those lines to complete (or not) the identification process. (skip next two steps).

Tag data: the operator annotates the display to indicate that the current data are associated with a particular ID,

ID source: if the information held uniquely identifies the source, the operator IDs the source and *enters the information into the log* and then resumes the search.

Search for other lines (data): If other lines should be expected to be present that are associated with the first line, then the operator searches for these specific lines proactively.

Sub tasks:

Select other beams

Scan other beams

Are all other lines(data) found? If the other expected lines are found, the operator can then *ID the source* and *Enter the log.* If the other expected lines are not found, the operator will *ID the source as possible,* then *Enter log* and then resume the search.

Are there other lines on beam? The operator returns to triple beam and checks to see if there are any further unaccounted lines on the current beams. If there are no lines then the search is resumed with a new triple beam set. If there are other lines, then the appropriate single beam is selected and the process repeated from that point.

6. The IPME model

In this section we outline the functionality of the IPME sonar model for the core tasks of searching for, and identifying, contacts of interest and building the underwater picture. and provide a high-level, but detailed description of how each function operates. A more detailed listing of the specific functions and logic is provided in Annex A and B.

The development of the IPME has followed the following steps, which are recommended in the IPME User's Guide.

6.1 Statement of the problem

The goal of the model is to look at the impact of some form of automated decision aid on the performance of a sonar system. In this particular case we have examined the impact of a semi-automated function to assist in the process of sanitising the array. The assessment of the performance of the modelled system under baseline and semi-automated conditions is achieved through a number of measures that are either performance based or operator based. The three major performance measures are *the number of log entries for lines,* the *total number of lines missed and the number of times the array is sanitised* per session. The operator measures are in terms of overall workload, and the sub-scale workload associated with visual, auditory, cognitive and psychomotor processes.

Thus, two IPME models will be constructed, one to generate baseline data for non-assisted decision making and the second, which incorporates the decision aid.

6.2 Analysis of the process

As indicated in section 5 above, the core processes have been identified and analysed in order to understand the process thoroughly and to determine the key tasks, the sequence in which they are performed, what resources they use, whether there are any restrictions on when they can be performed (for example, only when certain resources are available or after certain events have occurred), and how they affect the overall system being modeled. Validation of these core processes was obtained through a detailed review of the tasks by a highly experienced Navy Sonar Sea Trainer.

The next step in the analysis was to determine how the times for each task are distributed—that is, what probability distribution characterizes the task, and what values are appropriate for the distribution parameters (usually mean and standard deviation). An initial estimate of these parameters was made by HSI staff with some familiarity with sonar operations. Subsequently, these estimates were refined in consultation with the Navy SME.

6.3 The network diagram

The functions and tasks were then converted into a network diagram using IPME tools. The tasks could represent mental processes, physical processes, and processes that are not actually performed by anyone or anything. For example, we used a task to generate the sonar data that populates the model and another task to represent the process of making a decision that can result in several

possible alternative paths to following tasks. The Queue tool was also used to place queues in front of any tasks for which entities may need to wait.

The complete network diagram for the model is illustrated in Annex A.

6.4 Definitions: how tasks, decisions and queues operate

The information derived from the function and task analysis was used to define timing information, execution constraints, and the effects of the task on the system at large. Information about sub-networks (constraints on their execution) was also defined as well as routing decisions (decision type and routing conditions), and queues (their order, priority, and effects on the system). For each task function information could be provided for each of the following categories:

- Function name and number
- Description
- Triggering Conditions
- End conditions/consequences
- Properties: distribution shape, mean time, standard deviation, probability of failure
- Consequences of failure: task affected, percent time or failure degradation
- Workload rating (see Table 1: visual, auditory, cognitive, psychomotor)

The information entered was based upon HSI knowledge base and expert input provided by the sonar SME.

Details of these functions definitions are provided in Annex B.

6.5 Definitions: scenario events.

Scenario events provided a way to assign values to variables independent of when an entity begins or ends a task or enters or departs a queue. The expression assigning the value could be scheduled to occur at a specific clock time or when a specific condition is met in the task network model. Events could be defined to represent different scenarios for the process that was modeled thereby allowing one task network model to represent differences within your process instead of having to develop completely different network models.

6.6 Definitions: the variables and system changes.

Once the elements in the network diagram were defined parameters and starting values for global and local variables were established. In addition to these variables, other system characteristics that should be represented with variables were identified as well as all important counts and measurements that change as the simulation progresses. All changes in the value of each variable as task or queue effects were also identified.

6.7 Definitions: custom functions

Specific definable functions that are called in tasks, queues, or scenario events were developed as required.

Definitions for each of the above Model categories are provided in Annex B.

6.8 Definitions: the environment model

IPME allows a detailed description of the task environment to be included into the overall IPME model and which will impact upon the model performance according to predefined algorithms. The values were selected by members of the HSI team familiar with Navy operations and then validated by a Navy SME. The values were intended to representative a normative state, rather than a worst-case scenario. They may be easily manipulated in the future if one wished to look at the effects of degraded operational conditions upon system performance. Definitions for the environmental model are provided in Annex C.

6.9 Definitions: the crew model

The crew model was defined using a similar process to that of the environmental model, again assuming normative conditions. Details of the crew model are to be found in Annex E.

6.10 Workspace and micro models

IPME allows a simulation of the exact workspace to be constructed based upon measurements of the work space and the locations of smaller areas and objects with respect to the larger ones. It also allows sub-tasks such as keyboard entry, mouse manipulation, eye and head movements to be modeled at a micro level.

Given that the intention of the current project was to build a *generic* representation of a sonar system, it was deemed inappropriate to consider extending the analysis down to the level of defining a specific workspace and identifying the precise motor tasks that would be required to support task execution. Particularly, since the operator machine interface could be optimized in a variety of modes that could include touch screen, smart menus, voice interaction, display filtering etc.

6.11 Error checking

As the model was developed, the built-in error checking system was used to help locate errors in the model. Errors could be in lower-level logic such as tasks and sub-networks that are not connected, queues with no release condition, or undefined variables. Expressions were also checked for syntax errors. The model was also independently reviewed by another SME to check for errors.

6.12 Running and debugging the model.

As the model runs, variables were displayed to monitor their values, in addition the event queue was also displayed to allow us to monitor events as they are waiting to be executed. The trace file was also enabled to record the time when each task began and ended. These options helped us verify that the model was operating as intended, and identified where changes needed to be made. Once the model was running smoothly, snapshots were defined to collect values of variables at specified points during model execution. These provided further validation that the model was operating correctly and identified possible problem areas.

7. Automation

By automation, we mean the assignment of functions, which are now performed in an operator-intensive manner, to the system hardware and software, either fully or partially. As we have outlined in section 4.2, there exist many possibilities for automation that would lead to overall improvements of human-system performance. In consultation with the Scientific Authority, it was decided to select the task of *sanitising the array* (and its generic equivalent) as a first candidate for automation. There are several reasons for this. First, it is a highly critical task, which if not done correctly can result in degraded detection and identification of contacts. Second, it is a labour intensive process that may be subject to operator error. Third, it is a time consuming and repetitive process that consumes valuable operator resources. Fourth, it does not require of the operator much in the way of a cognitive effort (a "brain dead" task). Thus, a system in which the operator workload and potential for error is significantly reduced would free up the operator to perform more complex tasks, which in turn could result in higher levels of motivation and vigilance.

Before considering how such automation would affect the functions to be performed and the flow of information, it would seem appropriate to consider another strong candidate for automation, namely the entry of, and data retrieval from the log. This task shares many of the undesirable characteristics of the task of sanitisation in that it is repetitive and has low cognitive demand, yet is a critical function to the correct operation of the system. Post-mission analysis of the accuracy of the log (against ground truth from sonar data recorded during the mission) suggests that error rates may be as high as 20%[2]. Such error rates in data entry will then subsequently affect analysis and identification resulting in potentially missed identifications, false alarms and incorrect identifications. Therefore, we will include the tasks of log data entry and look-up as part of the automation model.

Although we refer to the technology solution in this section as automation, what we are really describing is a process of machine-assisted decision making, rather than full automation. This seems a more realistic intermediate technology that could be implemented in the short term with few other complications ensuing, such as issues of operator trust in the automated process. A fully automated system of sanitising the array would eliminate completely the need for an operator to track lines associated with ownship and TG and might even suppress these lines from being displayed. Thus, the operator's only task might be to check the initial parameters settings of the automated process and then to verify at a regular interval that the process was running correctly and to fine tune the parameters as required. Instead of this fully automated process, we have considered a smart decision aid to assist the operator and reduce both workload and the time required to perform the function.

7.1 Description of the model

The model will be described in detail in terms of the human components and how these components interact with the automation. There is no attempt to document how the automation will be enabled at a technical level. First, we will present a description of the two processes to be

[2] Based upon information provided by the Navy sonar SME

automated and then a revised information flow/decision-action diagram to show the entire search-identify process.

7.1.1 Semi-automated "sanitisation"

Create ownship/TG database: in order for the automation process to recognise ownship lines, a database will need to be constructed. The creation of this database could itself be a highly sophisticated, semi-automated function. In which case, operators might just enter the environmental and oceanographic conditions, names of ships in the TG, depth of the array and range sensing thresholds and spatial arrangement of the TG, planned vector of the TG and planned vectors of individual ships. The system would then compute which likely frequencies would be held on which beams and how these would change over time. Given that this degree of sophistication may require a degree of "machine intelligence" with associated programming capabilities that may be difficult and or costly to achieve, a simpler version of the database would appear to be a more attractive first option to contemplate.

The simpler database would comprise a history of the frequencies and beams associated with the TG that are manually entered and accumulated over time. Thus, given that the Canadian Navy might tend to patrol in standard TG configurations, the spatial relationship between the received sonar frequencies and beams and TG configuration could result in the creation of a series of templates. Thus, for TG configuration A, there would be a range of expected frequencies and bearings associated with each member of the TG.

Such a database would generate two new "operator functions" -create database for current mission and update database for local circumstances.

Update ownship/TG database: operator selects from a set of pull-down pre-configured lists of options appropriate settings for the current context. The list would include items such as: relevant oceanographic/environment conditions, TG configuration, TG speed and direction, expected detection ranges. These operations would require a minimum of keystrokes and alphanumerical data entry.

As an alternative, the process of updating the database could itself be highly automated whereby current TG data on position, speed, equipment in operation (i.e. noise sources) and oceanographic conditions could be directly incorporated into the database model from data already held in other databases within the TG.

For the purposes of our simulation and current model, we have assumed that the task of creating the database has been taken care of, and that the operator signing off the previous watch had updated the database. Thus, when the operator starts the new watch, the system is ready and prepared for the task of sanitizing the array. We assume that this procedure would be initiated with a simple menu selection and the system then displays the appropriate triple beam set that shows the data for the first TG member.

Review TG data for current context: The operator reviews the signature pattern against the data on the projected bearing generated from the database for accuracy against the current sonar data and fine tunes the database, as required. This could be considered an abbreviated version of the initial, operator-intensive task of "sanitising the array" and should result in considerable time saving compared with existing practice. Subsequently, this task will be repeated either as a pre-scheduled element of watch duty (say every 10 minutes), or the task could be triggered by changes in the TG configuration, or environmental conditions, or ownship/TG speed or array depth etc.

The results of this semi-automated process could be presented in a number of ways to the operator. The simplest way would be to have the system display lines automatically associated with ownship and TG using colour coding. This would make them readily distinguishable from other lines on a beam and would speed the search and identification for other lines. A second alternative would be to display all lines as they are currently (i.e. monochrome) but allow the operator to interrogate them by placing a cursor over the line. This would result in the presentation of a small pop-up window above the line that displays the contact/line association held in the database.

Once the data are correctly entered and appropriately configured for the current context, they are available for access on an ongoing basis as the operator interrogates each line on each beam.

Such a degree of automation runs the risk of inducing operator complacency and acceptance of the accuracy or truth in what is being displayed. Thus, other contacts (in particular hostiles), which have frequency characteristics in common with those being displayed as part of ownship/TG, run the risk of being overlooked for closer scrutiny and analysis. Therefore, there will be a need for the operator to conduct a proactive, verification check each time a tagged line is encountered before proceeding to the next line.

7.1.2 Semi-automated data logging and retrieval.

In present sonar operations data logging can be a manually intensive process that requires the operator to key in all of the required data with respect to environmental, oceanographic, array/sensor conditions as well as the data associated with the specific line of interest such as beam (bearing), frequency and possible source, if known. Data entry for the contextual information currently takes about 30 seconds with an additional 2-3 seconds for each line to be entered. This process could be semi-automated as follows.

Log data: The current environmental and contextual conditions would be presented in a pre-configured format and would only require data entry by exception. That is, if any of the conditions have changed since the last line logged, the operator would only have to enter the changes through a simple menu selection. The remaining part of the data entry could be accommodated by having the operator position the cursor over the line of interest, thereby allowing the system to capture the beam and frequency. The operator would then enter the contact information through a pre-configured set of options (e.g. trk#, poss/prob/unknown, friendly, neutral, hostile etc). Estimated time: 5-10 seconds.

Verify data: The operator reviews the data entered by the above procedure, modifies the entry, if required and then confirms the entry. Estimated time 5-10 seconds. Anticipated error rate: less than 1%.

Check log: similar to the process of displaying data for ownship/TG, the process of holding a cursor over a line of interest could result in a pop-up window above the line that shows the log data for that line. By selecting the track# for that line the operator could see all of the lines associated with the track highlighted on the display and could also review the time history of the track and lines in a separate window if required.

7.1.3 Semi-automated sanitisation: Information flow and decision/action diagram

The core function for the automated sanitisation process is "*Review TG data for current context*" and the detailed decomposition into the tasks and information flow for this are shown in Figure 5. A description and explanation of each of the tasks and decisions follows. As a starting point of the process we assume that a database of ownship and TG data has already been completed at some

prior point in time and has been recently updated by the outgoing watch. Thus, the first task of one operator on the new watch will be to check the information contained in the database.

The operator initiates the sanitise decision aid which displays the first TG signature on the appropriate beams, and the operator performs the following series of tasks. These tasks are repeated until all members of the TG have been accounted for.

Display data for ownship/TG. This is accomplished rapidly through the selection of a dedicated function key and the system automatically displays ownship or TG data on an appropriate beam.

Does pattern match lines displayed? The known signature pattern is shown overlaid on the beam data and the operator makes a visual pattern match with the sonar data on that beam. If the pattern matches, the operator proceeds to the next task. The number of lines to be matched depends on the overall volume of lines generated by the TG/ownship. For the purposes of the model, we have assumed either 25 or 100 lines are present on each beam from each TG ship. If the pattern matches, the operator proceeds to process other beams on which the data are found.

If the pattern does not match the data on the display, the operator *analyses the data* to determine whether the lines in question are likely coming from ownship (or TG(n)) and if they do, then *updates the database with the current ownship/TG data* to indicate any change in frequencies and proceeds to the next task. If they do not seem to be part of the expected pattern, the operator resumes with the next task.

We have arbitrarily set the probability that the lines will match as p=.85, on the basis that if the database is accurate and updated frequently, there would be a low probability of the data displayed being incorrect for the current circumstances. This number could be easily manipulated in the future to reflect lower probabilities associated with more dynamic movement among the TG members relative to the sensing array or changes in oceanographic conditions that may not have been incorporated into the current database model.

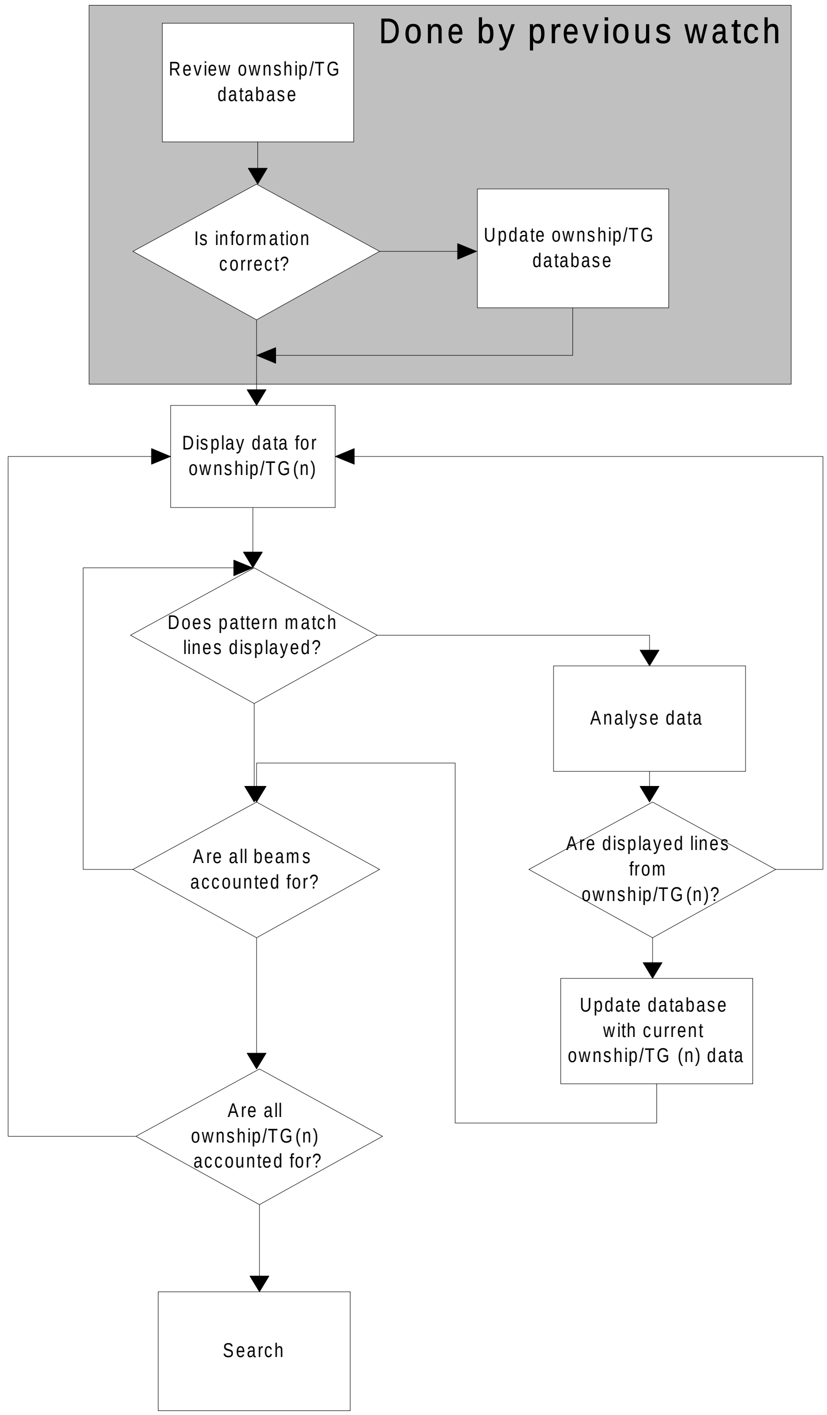

Figure 5: Information flow diagram of the semi-automated sanitise process.

Are all beams accounted for? Based upon the information in the database concerning the expected pattern, the operator will normally need to check other beams on which the ownship/TG data may be displayed. For the purposes of the model we have assumed that the lines are present on five different beams. If all beams are not accounted for the operator iterates through the steps in the process of reviewing the pattern for all remaining beams. Once all of the beams for that TG ship have been processed the operator goes to the next task.

Are all ownship/TG signatures accounted for? The operator checks to see if all signatures in the TG have been accounted for and iterates through the whole process until they are. This would be a fairly straightforward task that is prompted semi-automatically by the system. That is, the software controls the presentation for each successive member of the TG. Once all ships are all accounted for, the operator resumes the *standard search* through the display for sonar lines of interest.

8. Validation

The validation of the model was a two-step process involving intensive discussions with a senior Navy Sea Trainer responsible for sonar systems. In the first step and early in the project development, the overall sonar detection and analysis process was reviewed in depth and the roles and tasks of the operators fully decomposed and discussed. This initial process resulted in the generation of the basic search-detection model and provided ideas on critical tasks that would be suitable for assessing the effects of automation.

The second stage of validation required that the resulting IPME sonar model be thoroughly reviewed for accuracy and completeness. Three aspects of the model were reviewed with the sonar SME: (1) the system functions and information flow, (2) the times associated with the functions and expected error rates and (3) the visual, auditory, cognitive and psychomotor (VACP) workload ratings associated with each function. In particular, the semi-automated approach to sanitisation was reviewed in detail, since this was an "invention" of the HSI team and needed to be scrutinised by an SME.

Essentially, the basic system functions and their information flow were largely validated. A small number of functions were re-labelled and some were dropped or shifted among the operators. There were a significant number of changes made to the task timings and error rates, largely as a result of under-estimating the values in the initial model concept. There were minor and few changes to the VACP values.

The most significant outcome of the validation process was new information provided on the magnitude and scope of the sanitisation process. The number of ownship/TG lines to be analysed was severely underestimated in the model and we were given feedback that the number of lines varies enormously depending upon operational circumstances. The range could be anywhere between 25 to 200 lines per ship, which translates into 125 to 1000 for the TG. Further, these lines could be present on from 5 to 40 beams depending upon the specific oceanographic conditions and the distance and relative bearing of the TG from the sensor array.

The way an operator processes these data is to first pull up a bearing and then to use a harmonic or other smart cursor to identify the fundamental and related harmonics of each noise source on the ship. Once all sources have been identified on the beam in question they are logged and the operator moves onto other beams. Subsequently, the process of identifying the sources on the other beams goes somewhat faster in that the operator having identified the pattern already, can largely proceed with individual pattern matching on subsequent beams, supplemented by analysis where the pattern does not quite match.

As a result of this feedback on the volume of lines associated with the TG and the process used to analyse them, the IPME model was revised in agreement with the Scientific Authority. The revisions comprised two parts. First, instead of the model generating the large number of TG lines for operator processing and distributing these lines to different beams (and updating as the TG spatial relationships changed over time), the model was revised to reflect only the human operator component. That is, the times for the operators to perform the various tasks were modelled, with no underlying sonar data being "processed". The second aspect of the revision concerned what volume of line processing should be modelled. This decision is somewhat arbitrary as the model can be easily revised to incorporate other levels of loading. For practical purposes and to allow the simulation to run in a reasonable amount of time, we selected two levels of "line load" a low end

estimate of 25 lines per ship, each being represented on five beams, that is a total of 625 lines for the entire TG and sensor array, and a moderate to high level of 100 lines per ship. Our estimate was that the latter would take the operator over 7 hours to complete the task of sanitisation. Again it should be stressed, that the number of lines and beams carrying the lines are model parameters that may be easily changed in the future depending on the specific objectives in employing the model.

The feedback from the SME on the proposed semi-auto sanitisation process was very positive and the functionality was very much in line with what he envisaged would be an optimum approach. One function was removed from the initial process, which we had developed. This involved the operator checking for the possibility of other non –TG signatures that could be present on a beam which showed a similar pattern to a TG ship. The SME suggested that such a task would be assigned to the other operator as part of his responsibility for detecting and analysing non-TG data. As a result, this function was removed from the model.

9. Performance of the model

To evaluate the model, ten independent runs were conducted for each of the two levels of TG line complexity (25 or 100) and for the baseline and automated conditions. For each run, 30000 data updates were generated at a rate of 1 per second, thereby simulating 8.3 hours of real time operating conditions.[3] The complete dataset of performance data is being supplied in electronic format as an Excel spreadsheet file.

9.1 System performance measures

System measures comprised the following:

- Total number of contacts ID and logged- decomposed into
  - Total Source ID
  - Total Possible ID
  - Total Unknown ID
- Total number of lines missed
- Total number of wait lines (line is too short for operator to make decision)
- Total number of ignored lines (line is a noise transient)
- Total number of lines too far up the display to allow a decision
- Number of times the sanitisation process is completed

9.2 Operator measures

Operator measures comprised a continuous sampling of the following workload ratings:

- Visual
- Auditory
- Cognitive
- Psychomotor
- Computed Within task interference
- Computed Between task interference
- Overall workload index

Of the above measures, the following were excluded:

Computed Between task interference: operators were only allowed to do one task at a time – hence there could be no between task interference.

Overall workload index: without any effects of between task interference, the overall index is equivalent to the within task workload score.

[3] We should like to acknowledge the assistance of Braid Cain of DRDC-Toronto in conducting these data collection runs

9.3 Analysis and evaluation of model data

9.3.1 System performance measures

Because of the large amount of data generated and the redundant nature of some of the measures, we have selected three primary system measures as being the most representative and illustrative of any performance differences between baseline and automated conditions. These measures are total number of contacts logged, the total lines missed and number of times the array is sanitised per "watch"

The raw data, means and standard deviations for each of the ten runs are shown in the following tables, which compare manual (baseline) and automated conditions for both the 25 line and 100 line TG conditions.

Number of contacts logged

Run	TG=25 lines		TG=100 lines	
	Auto	Manual	Auto	Manual
1	53	36	41	33
2	50	35	40	35
3	49	36	40	34
4	50	42	42	35
5	53	39	39	34
6	49	39	42	32
7	50	37	40	35
8	51	37	42	34
9	48	36	40	32
10	56	36	43	34
Mean	50.9	37.3	40.9	33.8
SD	2.42	2.11	1.29	1.135

Table 4: Number of contacts logged: results of ten runs

These data and associated error bars (+/- two standard error based upon pooled variance) are illustrated in the following graph.

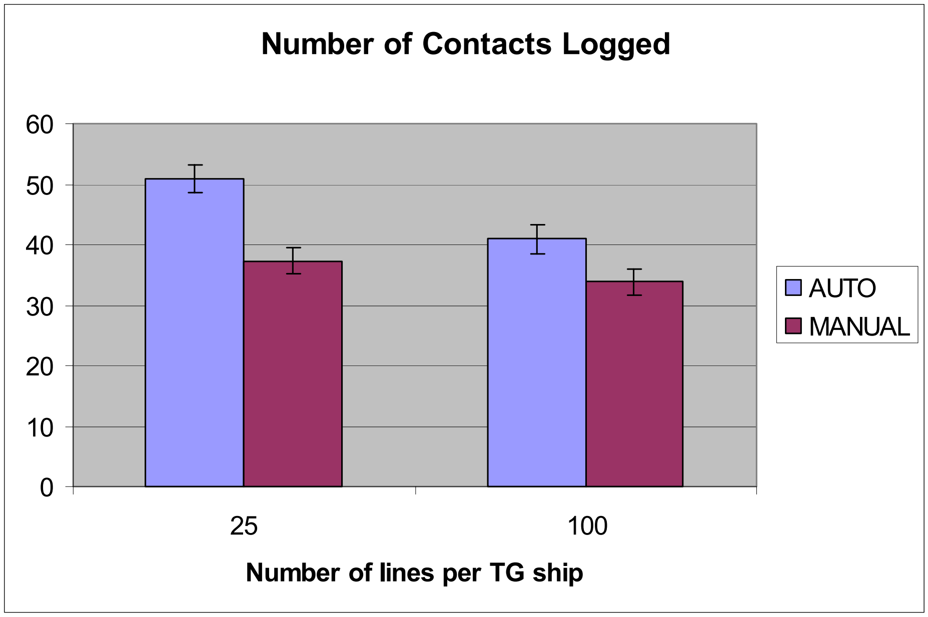

Figure 6: Mean number of contacts logged per condition: variance shown by +/- two standard error

Statistical analysis of these data show that for both the 25 line ($t=13.38$, $df=18$, $p<.01$)[4] and 100 line ($t=14.47$, $df=18$, $p<.01$) conditions there was a significant increase in the number of contacts logged when the task of TG sanitisation was semi-automated. This difference corresponds to gains of approximately 36% and 24% respectively for the 25 and 100 line conditions.

[4] A one-tailed test statistic was chosen since the difference between the two conditions was predicted in a specific direction.

Number of lines missed

Run	TG=25 lines		TG=100 lines	
	Auto	Manual	Auto	Manual
1	2571	2710	2676	2674
2	2596	2640	2694	2796
3	2591	2662	2674	2742
4	2674	2735	2641	2731
5	2537	2696	2650	2748
6	2637	2723	2739	2741
7	2619	2698	2616	2751
8	2576	2675	2655	2768
9	2580	2727	2663	2702
10	2510	2718	2657	2754
Mean	2589.1	2698.4	2666.5	2740.7
SD	47.14151	30.85882	33.11	33.63

Table 5: Number of lines missed: results of ten runs

These data and associated error bars (+/- two standard error based upon pooled variance) are illustrated in the following graph.

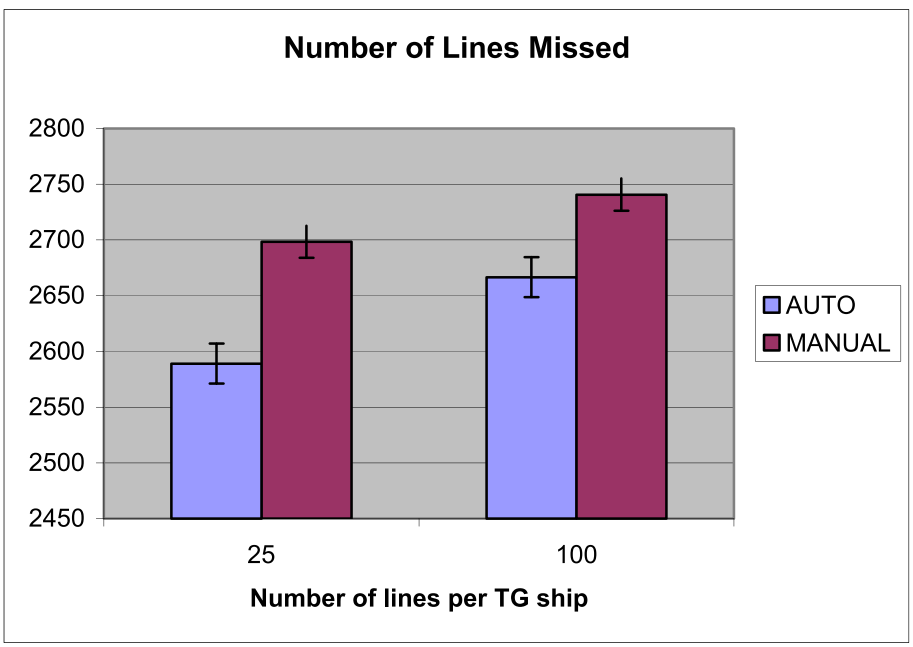

Figure 7: Mean number of lines missed per condition: variance shown by +/- two standard error

Statistical analysis of these data show that for both the 25 line ($t=6.13$, $df=18$, $p<.01$) and 100 line ($t=4.97$, $df=18$, $p<.01$) conditions there was a significant decrease in the number of lines missed when the task of TG sanitisation was semi-automated. This difference corresponds to gains of approximately 5.3% and 1.5% respectively for the 25 and 100 line conditions.

The number of times the TG data were sanitised

Run	TG=25 lines		TG=100 lines	
	Auto	Manual	Auto	Manual
1	16	4	8	1
2	17	4	8	1
3	17	4	7	1
4	17	4	10	1
5	18	4	8	1
6	18	4	8	1
7	17	4	8	1
8	17	4	8	1
9	18	4	7	1
10	17	4	8	1
Mean	17.2	4	8	1
SD	0.63	0	0.81	0

Table 6: Number times the TG data were sanitised: results of ten runs

Clearly, in light of the data, no statistical analysis is necessary to demonstrate the clear advantage of the semi-automated sanitisation process over the traditional manual approach.

9.3.2 Operator measures

Mean workload scores for each operator on each of the workload dimensions for each of the experimental conditions were computed based upon the individual 35225 values computed by the IPME model during each of the 10 runs. The means of the ten were then calculated and the ensuing data are shown in the following graphs. Note that Operator 1 performs just the basic search and identification task and that Operator 2 does the sanitization process (manual or semi-automated) and when finished, contributes to the basic search task. The data are presented separately for the two sanitisation conditions in which the number of lines per TG member was either 25 or 100 per beam.

Statistical analysis of the data was conducted using two-factor (level of automation and number of lines per TG ship) analysis of variance (ANOVA). Where necessary, supplemental comparisons were made using t-tests. It was decided that it would not be appropriate to combine all of the individual workload measures into a single multivariate analysis of variance, in view of the fact that the auditory workload scores showed opposite effects to the other measures and that the separate workload indices are theoretically uncorrelated. Similarly, no separate analysis was conducted of the total within-task interference workload, since this is not statistically independent of the other measures.

Operator 1

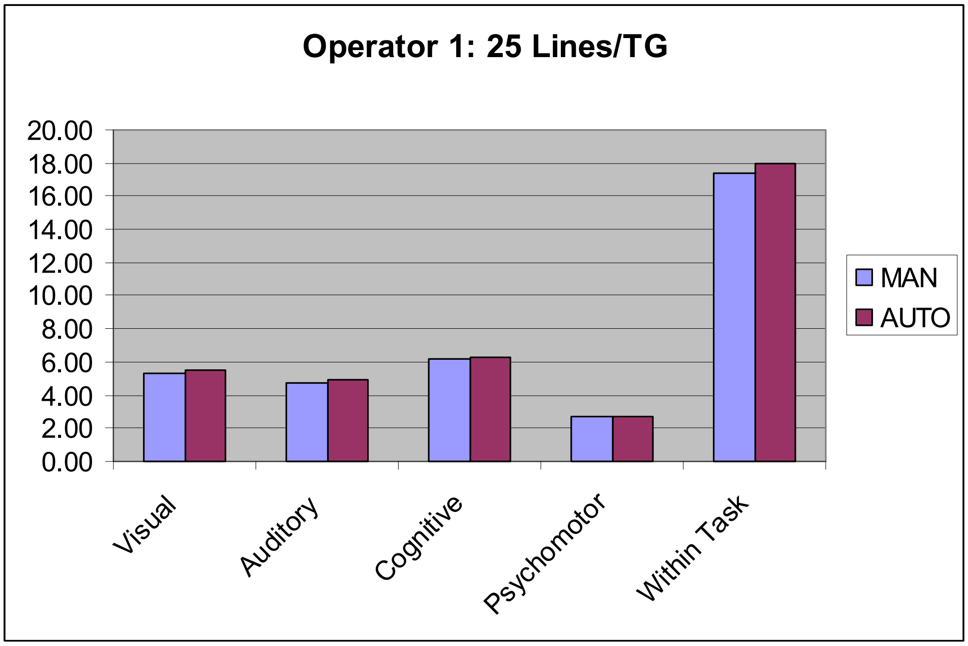

Figure 8: Operator 1: Mean workload ratings-25 lines/TG

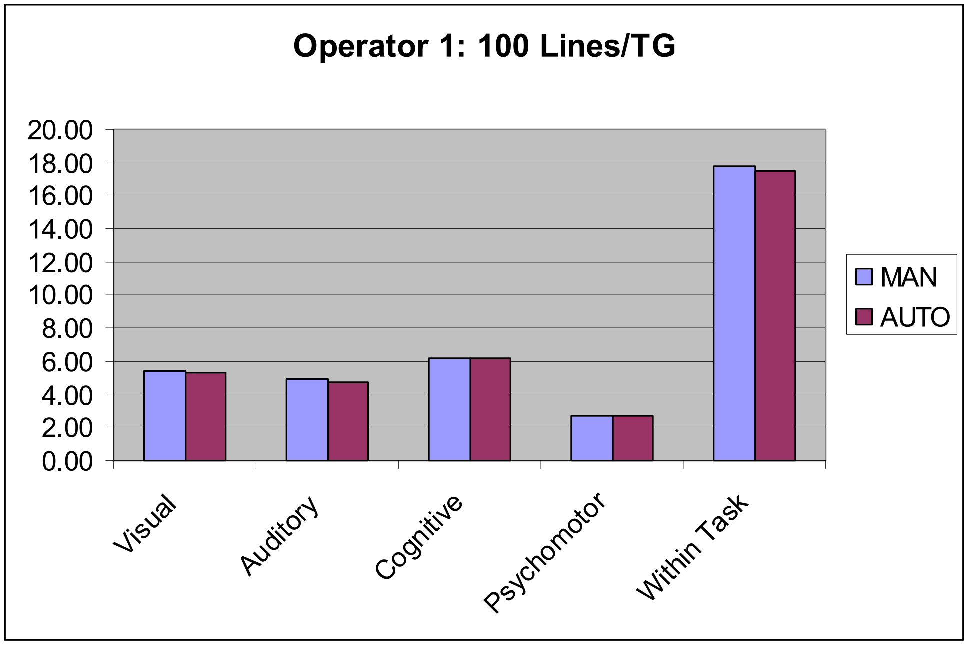

Figure 9: Operator 1: Mean workload ratings-100 lines/TG

The data show that the workload ratings are virtually same for both conditions of automation. None of the ANOVA showed any significant ($p<.05$) main effects or interactions. This is to be expected as this operator's tasks do not change, even when Operator 2 has more time available to work in parallel on the basic search, as should occur in the automated condition. In other words, Operator 1 still continues to work away and his/her task load is unaffected by any available capacity contributed by Operator 2. We should only expect to see any effect on Operator 1 under conditions when there are much fewer lines and Operator 1 runs out of lines to analyse and just performs the routine search, thereby reducing his time averaged workload for the entire session.

Operator 2

Similar data for this operator are shown in the next two figures.

For the both TG conditions, there seems to be a small trend for higher workload ratings in the manual condition for visual, cognitive and psychomotor components, and a reverse trend for the auditory workload component. The effect of the number of TG lines to be analysed was not consistent. For all workload measures except the cognitive (where the reverse was true), workload was slightly higher in the 25 line condition. However, these effects are quite small, typically of the order of less than .1 on the 10-point workload scale, but are statistically significant because of the small variance between simulation runs. The significant interactions for visual and cognitive workload scores reflected a larger effect of the automation condition under the 100 line condition, compared with the 25 line condition. This difference was in the opposite direction, however, for the psychomotor scores. The major statistical analyses supporting the above statements are shown in the following table.

Measure	Source	F (df for all= 1,36)	Significance
Visual	Number of lines	47.46	p<.01
	Automation	394.61	p<.01
	Interaction	56.33	p<.01
Auditory	Number of lines	1.42	NS
	Automation	126.21	p<.01
	Interaction	0.12	NS
Cognitive	Number of lines	216.09	p<.01
	Automation	831.92	p<.01
	Interaction	359.587	p<.01
Psychomotor	Number of lines	136.31	p<.01
	Automation	2049.38	p<.01
	Interaction	242.81	p<.01

Table 7: Summary of ANOVA results for workload ratings for Operator 2

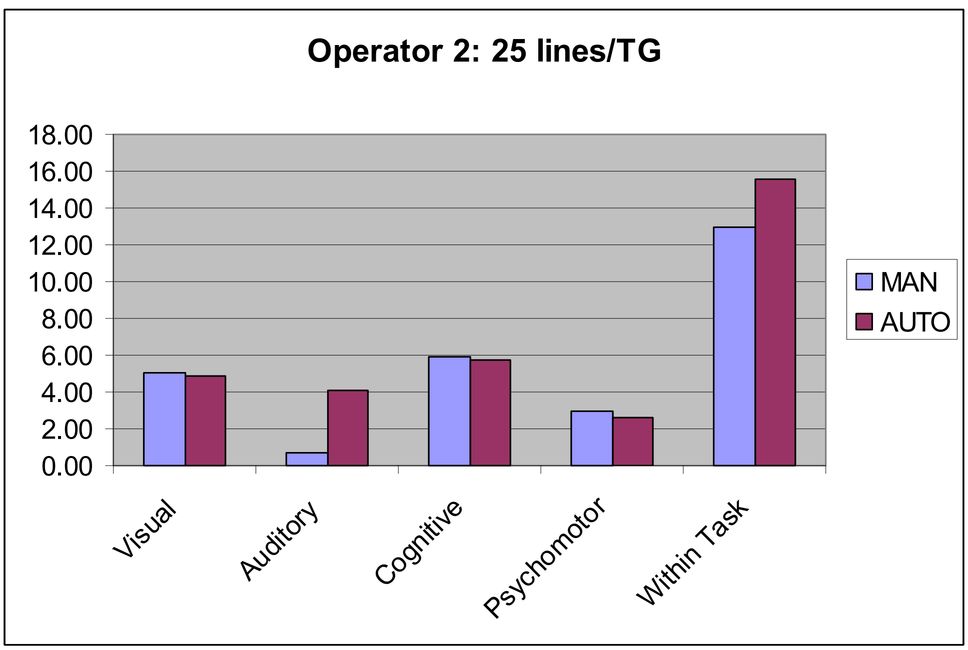

Figure 10: Operator 2: Mean workload ratings-24 lines/TG

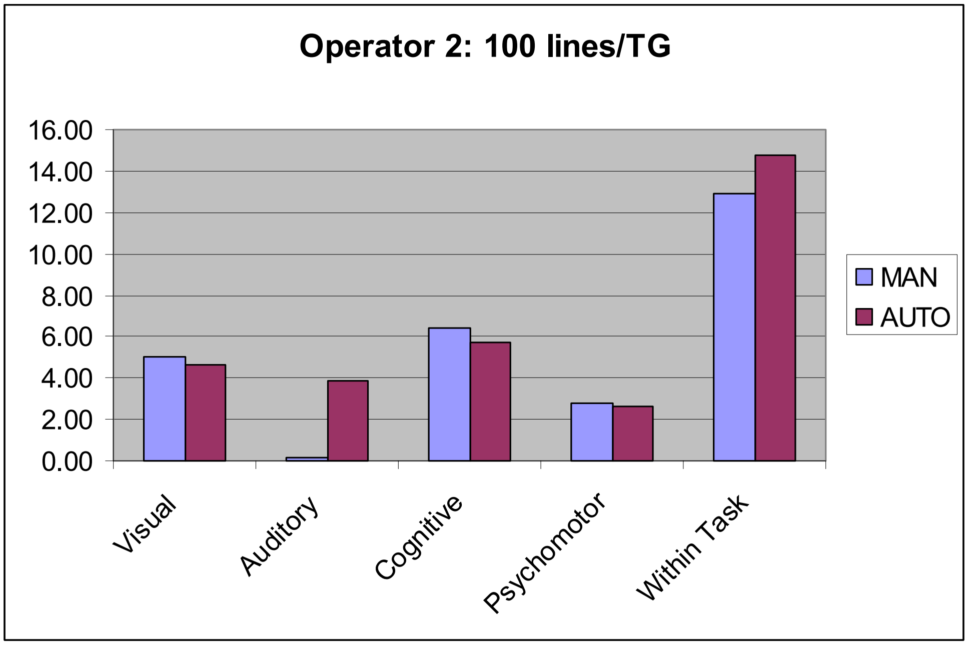

Figure 11: Operator 2: Mean workload ratings-100 lines/TG

To return to the effect of automation, we were surprised initially to have found the large effect in the auditory workload component in a counterintuitive direction, which also has a strong influence in making the composite within-task workload measure go in the same direction. In order to explore this further, we looked at the second-by-second underlying auditory data (from which the means are calculated) and found that for the automated condition, the operator spends on average approximately 63% of the time doing some form of auditory analysis, whereas in the manual case this figure is about 12% of the time. Thus, the advantage of the automated condition is that it allows the operator to process more lines generally and as a result, more frequent auditory analysis results, which in turn affects the time averaged mean.

Overall, we do not find large effects on workload resulting from the automation process, even though the effects are statistically significant. This is not surprising since the operators in the auto condition are simply doing more or less the same tasks, but performing them more frequently as a result of the more efficient process. We should only expect a large effect of workload between the two conditions to emerge when the operators are less loaded, i.e. there are fewer lines to process. In such a case, the operator in the automated condition would process all of the lines faster, and, once all lines have been accounted for, would have only a basic surveillance function to perform, which in itself would carry a lower workload.

10. Summary

This project has demonstrated that the complex task of conducting sonar surveillance, target detection and identification can be successfully simulated with a task network model. The purpose of the model is to allow "what-if" questions concerning system redesign to be answered a priori without the need to actually implement the proposed changes. In principle, the model that has been developed could be readily modified to address the following influences on system performance and operator workload:

- The number of operators
- The number and size of screens
- The value of smart tools or decision aids
- Re-assignment of tasks among the team
- Operator processing and analysis re-engineering

In addition to such system-based changes, environmental influences may also be manipulated such as the rate and number of targets, the rate of system updates and the signal to noise ratio.

As a demonstration, we have shown that the basic model can be adapted to incorporate a semi-automated function to assist operators in the time consuming, repetitive and mentally unchallenging task of sanitising ownship and TG lines from the detection array. This model has been tested and run through several trials to generate output data that shows the impact of the automation aid. This impact is shown to have a somewhat larger effect on system performance measures than on operator workload. The size of the impact on system throughput (21%-36% more lines logged, 8 times more sanitisations achieved) is probably of significant operational importance and suggests the potential value in a system re-design that incorporates such a decision aid. The effects on operator workload, however, are largely dependent upon the environmental parameters selected to load the operators. In the present case, based upon SME advice, we chose to simulate low-medium and medium-high loadings on the system, in terms of the lines that were to be processed.

The validation process that was undertaken provides some general assurance that the tasks, their sequences, the decisions and actions are all consistent with existing sonar processing practices. However, it should be remembered that the specific parameter values chosen for the sonar data,represent exemplars of operational values and cannot be considered to reflect the true range of sonar contact data that is found under a wide variety of operational and environmental conditions.

It should be noted that the values selected for the crew and environmental models are provided as context for the core IPME model, but do not in themselves influence the performance of the model. The development of functions that compute the effects of critical influences remains an ongoing process by the IPME development teams and the ability to incorporate sonar-critical, environmental and crew factors into the model in the future, would greatly enhance the model's generalisability and utility.

11. Limitations and Constraints

11.1 Scope

The particular area of sonar analysis chosen for modelling represents just one small aspect of the overall functions and tasks performed within the typical sonar suite (see figure 2). As such, it cannot claim to comprehensively represent this entire process. However, it does faithfully represent the core critical task of the detection and identification of sonar narrow-band data associated with contacts of interest.

11.2 Sonar data

Throughout the description of the model we have referred to the sonar acoustic data as "lines", to be consistent with the terminology and concepts of CANTASS. However, there is nothing in principle that constrains the data to being the equivalent of lines. The core sonar data could have a variety of different characteristics both spatial and temporal, as long as the key functions to be performed by the operator were detection and analysis.

11.2.1 Spatial and temporal characteristics:

The parameters for these were chosen to be illustrative of actual data found in some operational conditions. The specific values chosen influence the performance of the model. For example, changing the mean duration a line is available to be detected and its spatial distribution on the sensor array will greatly influence the number of lines that an operator is able to process. Further, changing the number of lines that must be "analysed" by the operator in order to identify a target will also have a large effect on system throughput measures.

11.2.2 Target data density

Variation from the particular values chosen will cause the workload on operators and their simulated performance to change that observed. A lower target rate would result in operators spending more time in search and less time in identification, with a consequent effect on associated workload scores.

11.3 Operator characteristics

The values chosen for tasks such as contact detection rates, the probability of having sufficient evidence to identify, the probability of encountering noise and the probability of having a target scroll off the screen all effect system throughput. They provide a convenient baseline for the comparison of changes in system performance as a function of manipulating independent variables of interest. As such, they should not be taken to be representative of actual operator performance under similar operational conditions, nor should they be regarded as normative of absolute benchmarks of performance.

Similarly, while the values chosen for means, distributions, standard deviations and error rates for operator tasks were based on broad operational considerations, other values may also be

appropriate depending upon the concept of task environment and would have a significant effect on operator performance and workload.

11.4 Task and information flow

The sequence of tasks performed by the simulated operators closely resembles the concept of operations employed for the detection and identification of narrow band sonar data in CANTASS. However, it should be noted that this sequence of tasks and their distribution among the operators is only one of many that might be adopted. The present model only permits operators to "perform" in a somewhat routine, serial manner. It does not allow for task prioritization, task interruption, trading tasks between operators, co-operative tasking or task backtracking.

11.5 Length of watch

A watch length of just over eight hours was simulated. This value is a key determinant of the overall success in sanitising the array, which can be a process that takes hours rather than minutes. Thus, selection of watch lengths that are much shorter will give misleading information on the comparison of sanitisation performance between manual and automated conditions.

11.6 Simulation of mental processes

There is no attempt in the model to further decompose some complex tasks into the sequential steps and associated mental activities that are required for their successful execution. An example of this is the function "*Is there any other evidence?*", which incorporates a variety of sub-tasks that involve checking other sources of information such as intelligence, listening to the acoustic signal compiling and analysing evidence for a particular identification and using a decision rule to make the judgment. Each of these tasks in themselves may be complex, have a variety of time distributions for task completion, have different error rates and carry somewhat different workload ratings. Hence, the generic representation of all of these task elements into a single function may carry some risk since the factors that influence these tasks differentially, may not be reflected in the model performance.

12. Suggestions for future work

Two areas suggest themselves as the next logical step to follow the current work – (a) the extension and refinement of the model and (b) model validation.

12.1 Extension and refinement of the model

The following points represent opportunities to enhance the model scope, generality and fidelity.

- Simulate directly the tasks of detection, analysis and identification (and associated sub-tasks and operator mental processes), as compared to using general performance shaping metrics, as is the case with the present model.
- Simulate acoustic data analysis
- Extend the model to include classification
- Extend the model to include tasks performed by the Sonar Supervisor and ASWC
- Examine effects of other decision aids such as: identification assistance tools, classification aids and data tagging and automated logging

12.2 Model validation

The basic model functions and their associated timings, logic, failure rates, consequences and associated workload have received nominal validation through discussions with a sonar SME. This validation is based upon one experienced individual's judgment of the appropriate values. To improve the validity of the model several options are feasible. First, we could collect real-time data (task timings, accuracy, error rates and workload) for the core tasks in an operational context. However, this is practically and logistically difficult to accomplish. Second, we could attempt to find other SMEs, with a similar background and experience judgments to the present SME, to provide additional data. However, such individuals are difficult to locate, are very busy and may be so few in number that validity cannot be really enhanced to any acceptable statistical degree. The third approach would be select critical components of the model to be validated in an experimental paradigm that uses some of the basic task components of identification and analysis process. This approach would involve developing tasks that are highly similar to the model core tasks, but which could be performed by non-Navy subjects with sufficient training. The objective would be to collect both performance data and workload ratings, so that these two critical aspects of the model could be independently validated.

The experimental paradigm should probably focus on the following core characteristics of the model:

- Search across a number of display windows
- Detection of lines in noise
- Analysis of multiple line sets to arrive at an identification
- Use of ancillary data to provide a complex task of information assembly to arrive at an identification
- Logging of data
- Search of the log
- Comparison of the manual and semi-automated sanitisation process using a facsimile task
- The design of the semi-automated decision aid for sanitisation and the estimates of task timings adopted in the model for the processes involving the aid

13. References

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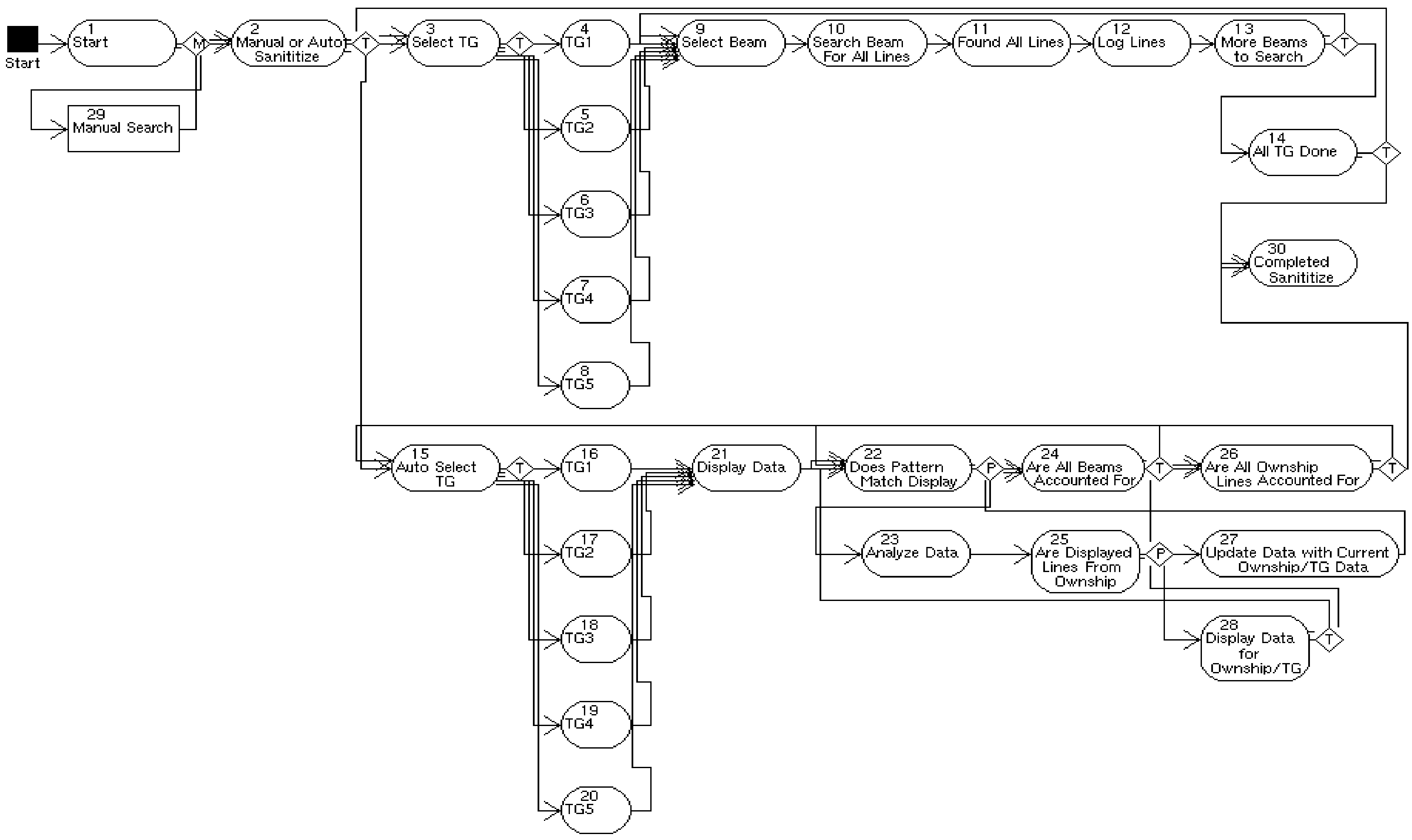
14. Glossary

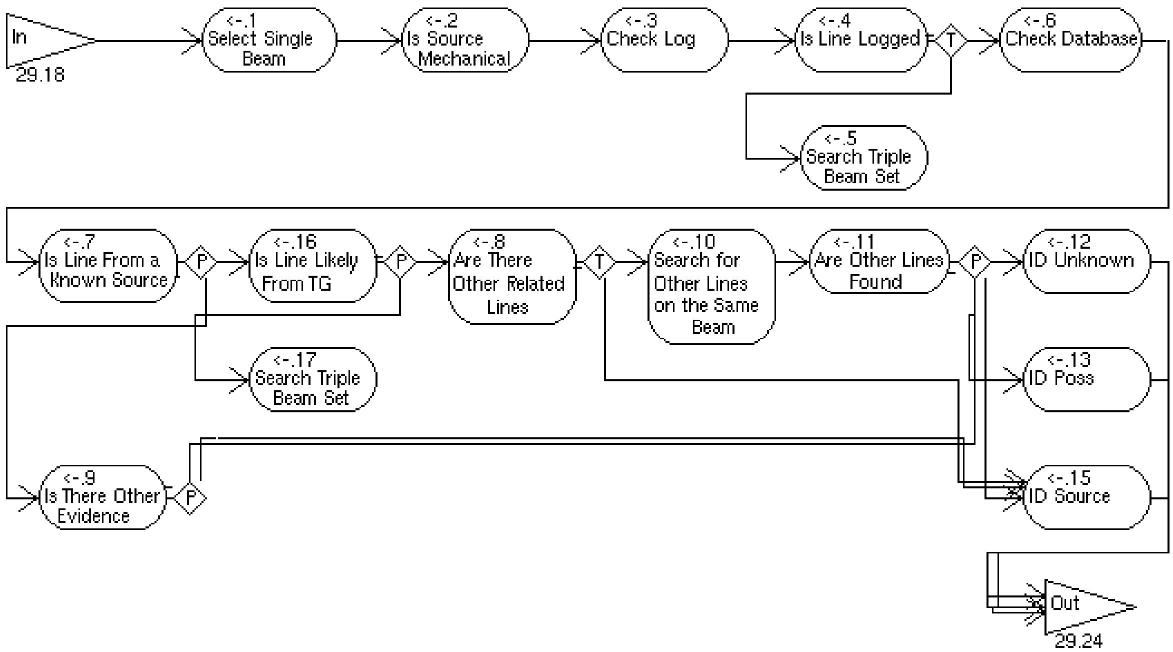
ASWC	Anti Submarine Weapons Commander
CANTASS	Canadian Towed-Array Sonar System
HCI	Human-Computer Interaction
ID	Identify
IPME	Integrated Performance Modelling Environment
PSF	Performance Shaping Function
SA	Scientific Authorty
TAP	Threat Assessment Pack
TIAPS	Towed Integrated Active Passive System
TG	Task Group
VACP	Visual, Auditory, Cognitive, Psychomotor (workload dimensions)

Annex A. Description of the logic and functions of the IPME Sonar Model

The overall IPME model is shown on the next page as a task network diagram.


Start
1 Start
29 Manual Search
2 Manual or Auto Sanititize
3 Select TG
4 TG1
5 TG2
6 TG3
7 TG4
8 TG5
9 Select Beam
10 Search Beam For All Lines
11 Found All Lines
12 Log Lines
13 More Beams to Search
14 All TG Done
30 Completed Sanititize
15 Auto Select TG
16 TG1
17 TG2
18 TG3
19 TG4
20 TG5
21 Display Data
22 Does Pattern Match Display
23 Analyze Data
24 Are All Beams Accounted For
25 Are Displayed Lines From Ownship
26 Are All Ownship Lines Accounted For
27 Update Data with Current Ownship/TG Data
28 Display Data for Ownship/TG
M
T
P

Decomposition of the function "Manual search"



Function descriptions

Task Event #	Task Title	Task Description
1	Start	This task uses a multiple decision to initiate the scenario by directing a sonar signal to both OP2 (to start the Sanitization process) and OP1 (to start the Basic Search process). This task also sets Sanitize Mode ON. With Sanitize Mode ON, Operator1 is responsible for searching for lines on every beam in the display while Operator2 attends to Sanitizing the array. Operator2 is set to beam zero, so Operator1 is able to search every beam in the array without overlaping with Operator2.
2	Manual or Auto Sanitize	This task prevents the initial sonar signal from entering the Sanitize task until the scenario time has reached 300 seconds. During the first 300 seconds of the scenario, lines populate the triple beam display in the Basic Search process. The Operators start searching the display once 300 seconds has passed. The value of the TG (current Task Group member) variable is set to 0 to begin the Sanitization process. A tactical decision sends a one tag to either the Manual Sanitize process or the Auto Sanitize process depending on the value of the variable named "manualSanitize". If manualSanitize is set ON (is equal to 1) the tag is directed to the Manual Sanitize process. If manualSanitize is set OFF (is equal to 0) the tag is directed to the Auto Sanitize process.
Manual Sanitize		
3	Select TG	This is the first task in the Manual Sanitize process. The value of TG (current Task Group member) is incremented by 1 to advance the Operator to sanitize the next TG. The number of beams remaining for the next TG member is set to 5. The value of the variable named "experimentMode" sets the number of lines per beam to either "Low" or "Medium". If the value of experimentMode is equal to 1 the number of lines per beam is set to "Low". If the value of experimentMode is equal to 2 the number of lines per beam is set to "Medium". A tactical decision routes the tag to the appropriate TG member (TG1 to TG5) depending on the current value of the TG variable. As the Sanitization process progresses and the Select TG task is revisited, the value of TG is incremented by 1 to instruct the Operator to identify the next Task Group member.
4 to 8	TG1 to TG5	These tasks route tags to the "Select Beam" task. This task provides a visual indication during animated playback to indicate what TG member is currently in the process of being detected.
9	Select Beam	The functions named SearchTime() and LogTime() are called by this task. These functions assign values to the variables named searchTime and logTime, respectively. The value of the experiment variable named "experimentMode" sets the number of lines per beam to either "1" or "2". If the value of experimentMode is set to 1 ("Low") there are 25 lines per beam. If the value of experimentMode is set to 2 ("Medium") there are 100 lines per beam.

Task Event #	Task Title	Task Description
10	Search Beam for All Lines	Mean time for this task is set according to the value of a variable called searchTime. If number of lines per beam is set to 25, the mean time is 300 seconds for the first beam encountered and 180 seconds for each beam afterward. If number of lines per beam is set to 100, mean time is set to 1973 seconds for the first beam encountered and to 720 seconds for each beam afterward.
11	Found All Lines	The task mean time is set to 2. A fixed link from this task directs the tag to the "Log Lines" task.
12	Log Lines	Mean time is set according to the value of a variable called logTime. If number of lines per beam is set to 25, mean time is set to 30. If number of lines per beam is set to 100, mean time is set to 60.
13	More Beams to Search	The task mean time is set to 2. The value of the variable named "remainingBeams" is decreased by one to advance the Operator to sanitize the next beam for the current Task Group member. A tactical decision following this task routes lines to either the "Select Beam" task if remainingBeams has a value greater than 0 (i.e. there are more beams left to search for the current Task Group member) or routes line to the "All TG Done" task if remainingBeams has value equal to zero (i.e. there are no more beams left to search for the current Task Group member).
14	All TG Done	The task mean time is set to 2. A tactical decision following this task routes lines either to "Completed Sanitize" if the variable called TG is equal to 5 or to "Select TG" if TG is less than 5.
Automated Sanitize		
15	Auto Select TG	This is the first task in the Automated Sanitize process. The number of beams remaining for the next TG member is set to 5. The value of the variable named "experimentMode" sets the number of lines per beam to either "Low" or "Medium". If the value of experimentMode is equal to 1 the number of lines per beam is set to "Low". If the value of experimentMode is equal to 2 the number of lines per beam is set to "Medium". A tactical decision following this task directs the tag to the appropriate "TG#" task (ie. TG1 to TG5) depending on the value of the TG variable.
16 to 20	TG1 to TG5	This task routes the tag to the "Display Data" task. This provides a visual indication during animated playback to indicate what TG member is currently in the process of being detected.
21	Display Data	The task mean time is set to 2. A function named "AutoTimings" assigns values to variables that are used as task mean times for tasks 22 (patternTime), 23 (analyzeTime), and 27 (updateTime). Task mean times are set according to the value of the "experimentMode" variable (i.e. number of lines per task group member). If 25 lines per beam are used, mean times are set to a baseline level. If 100 lines per beam are used, mean times are increased by a factor of 4 times.
22	Does Pattern Match Display	The task mean time is set according to the value of a variable named "patternTime". If there are 25 lines per beam, mean time is set to 10. If 100 lines per beam, mean time is set to 40. The standard deviation is set to 2. This task updates the value of the variable called "currentBeam" with the value of the array variable called "remainingBeams". The value of remainingBeams is decreased by one to advance

Task Event #	Task Title	Task Description
		the system to sanitize the next beam for the current Task Group member. A probabilistic decision following this task routes tags to the "Are All Beams Accounted For?" task 75 percent of the time [i.e. Pattern does not match lines displayed] and to "Pattern Matches Lines Displayed" task 25 percent of the time.
23	Analyze Data	The task mean time is set according to the value of a variable named "analyzeTime". If there are 25 lines per beam, mean time is set to 60. If 100 lines per beam, mean time is set to 240. The standard deviation is set to 12. Fixed link to "Are Displayed Lines From Ownship/TG?"
24	Are All Beams Accounted For?	This task evaluates whether or not all five beams for the current Task Group member have been examined. The task mean time is set to 2. The value of "currentBeam" is updated by the array variable "remainingBeams". A tactical decision following this task directs the tag to "Are All Ownship/TG Lines Accounted For?" if the value of the array variable called "remainingBeams" is greater than 0. If "remainingBeams" is equal to 0, the tag is directed to "Does Pattern Match Lines Displayed?"
25	Are Displayed Lines from Ownship?	The task mean time is set to 2. A probabilistic decision following this task directs the tag to "Display Data For Ownship/TG" task 85 percent of the time to indicate the lines are attributed to Ownship or Task Group. Alternatively, 15 percent of the time the decision the tag directs to "Update Database with Current Ownship/TG Data" to indicate the lines are not attributed to Ownship or Task Group.
26	Are All Ownship/TG Lines Accounted For?	The task mean time is set to 2. A tactical decision following this task directs the tag to "Completed Sanitize" task if the value of TG equals 5. The tag is directed to "Auto Select" to advance to the next Task Group member if TG is less than 5.
27	Update Data with Current Ownship/TG Data	The task mean time is set according to the value of a variable named "updateTime". If there are 25 lines per beam, mean time is set to 30. If 100 lines per beam, mean time is set to 120. A fixed path from this task leads to "Are All Beams Accounted For?"
28	Display Data for Ownship/TG	The value of the variable named "currentBeam" is updated by the array variable "remainingBeams" to update the number of remaining beams to search for the current Task Group member. A tactical decision following this task directs the tag to "Are All Ownship/TG Lines Accounted For?" if the value of the array variable remainingBeams is equal to 0 (ie. The final beam for the current Task Group member has been examined). The tag is directed to "Does Pattern Match Lines Displayed" if remainingBeams is greater than 0 (ie. More beams for the current TG member remain to be examined).
Sanitize Complete		
30	Completed Sanitize	This task occurs when the Operator has completed the Sanitization process. The timeSanitized variable is set to the current time. The TimeSanitizedFN function increments and sets the appropriate variable (e.g. FirstTimeSanitized, SecondTimeSanitized, etc.) to record the current time. The variable sanitizeReset is incremented by one. The value of the variable "On2Detect" is set to 1 to enable

Task Event #	Task Title	Task Description
		is incremented by one. The value of the variable "Op2Detect" is set to 1 to enable Operator2 to detect lines in the Basic Search process. The value of sanitizeMode is set to 0 to activate the OpBeam Function and to enable Operator2 to examine Beam number 43. The Sanitization process terminates at this task and Operator2 joins the Basic Search process.
29	Manual Search (Group Network)	This task is triggered at the start of the simulatiion. It directs a tag to the Basic Search process to begin generating lines on the array.
Basic Search		
29.1	Generate Sonar Signal	This task increments the tag variable to continuously generate sonar signals for the Basic Search process at a rate of one new signal every 10 seconds. Reducing this mean will increase the number of lines per second generated by the model. A function called TypeFN assigns one of four possible signal types to the tag (e.g. Real Signal of Interest [identify], Noise [ignore], Partial Incomplete Signal [wait], Expired Signal [proceed to next]). The TypeFN function generates a random number between 1 and 9 that is coded to a signal type. Numbers 1 and 2 are coded as "Real" sonar signals generated by a mechanical source. Real signals are lines repeated over several cycles of the sonar display. Numbers 3, 4, and 5 are incomplete lines which are not yet identifiable because they are not long enough to distinguish between signal or noise. These incomplete lines could be real, transient, or noise signals. The operator must wait for more sonar display cycles before making this determination. Numbers 6 and 7 are
29.2	Select Triple Beam Set	The mean time is set to 1.5 with a standard deviation of 0.15 seconds. The variable named totalLines is incremented by 1 to count the number of lines generated by the model. A tactical decsion following this task directs the line to the appropriate beam according to the array variable named beam.
29.3 to 29.17	Beam 1-3 Examine to Beam 43 Examine	The task mean time is calculated using a formula based on the number of lines on the beam (4 + #lines^1.3). The task mean time is set to 0 if the tag has passed it's expiration time. The value of beam[beam#] is set to 1 when a line enters the task and 0 when the line exits the task to ensure the operator is only able to examine one line at a time. The value of Op#Buffer is updated by the value of buffer{beam#] and Op#Tags is updated by the value of beam[beam#] value. These variables are used to determine if there are any lines currently being examined on the current beam. An array variable named Op is used to associate the current line to the Operator who detected it so all tasks carried out involving this line assign workload to the correct Operator. A variable named die is updated by the array variable expiration[tag] to display the expiration time for the current line. A tactical decision following this task directs the line either to "Missed" if the value of the array variable expiration[tag] is le

Task Event #	Task Title	Task Description
29.18	Signal or Noise	The task mean time is set to 10. This task updates the value of the variable called "classifyType" with the value of the array variable called "type[tag]" to display the type identity of the line (e.g. Signal, Transient, Noise, etc.). The value of Op#Detect is set to 0 to prevent the current Operator from detecting additional lines during the identification process. A tactical decision following this task directs the line depending on the value of the variable named classifyType. The "Select Single Beam" branch is followed if the line is type 1 or 2; the "Wait" branch is followed if the line is type 3, 4, or 5; the "Ignore Noise" branch is followed if the line is type 6 or 7; and the "Go To Next" branch is followed if the line is type 8 or 9. An alternative branch leading back to "Start" is followed if 600 seconds have passed since the Sanitization process has been completed and the current Operator is Operatior2. This branch restarts the Sanitization process and removes Operator2 from the Basic Search
29.19	Missed	This task is designed to count the number of missed lines. The value of the variable named "missed" is incremented by 1 each time a line arrives at this task. The value of Op#Detect is set to 1 to allow the Operator to examine the beam.
29.21	Ignore Noise	This task is designed to count the number of noise signals detected by the Operator. The value of the variable named "ignored" is incremented by 1 each time a line arrives at this task. The value of Op#Detect is set to 1 to allow the Operator to examine the beam.
29.22	Wait	This task is designed to count the number of incomplete lines detected by the Operator. The value of the variable named "wait" is incremented by 1 each time a line arrives at this task. The value of Op#Detect is set to 1 to allow the Operator to examine the beam.
29.23	Go to Next	This task is designed to count the number of lines which have started to disappear off the top of the display and moved to the next beam. The value of the variable named "gotonext" is incremented by 1 each time a line arrives at this task. The value of Op#Detect is set to 1 to allow the Operator to examine the beam.
Identification Process		
29.20	Select Single Beam (Group Network)	Directs the tag to the Identification process.
29.20.1	Select Single Beam	The task mean time is set to 2 with a standard deviation of 0.4 seconds. This task has a fixed link to the task "Is Source Mechanical?"
29.20.2	Is Source Mechanical?	The task mean time is set to 5. This task has a fixed link to the task "Check Log"
29.20.3	Check Log	The task mean time is set to 20 with a standard deviation of 5. This task has a fixed link to the task "Is Line Logged?"

Task Event #	Task Title	Task Description
29.20.4	Is Line Logged?	The task mean time is set to 0.5 with a standard deviation 0.005. The task calls a function named "SubDetect" that identifies the beam where the current line was detected and calls a function named "Sub[beam#]Contact" which identifies the line frequency (ranging between 1 and 10), records the line in computer memory by incrementing the value of the variable named "det[beam#]_freq[frequency#]" by 1, and calls another function named "Sub[beam#]Log". The function called "Sub[beam#]Log" examines the number of times each line on the current beam has been logged. If all 20 lines on this beam have been logged (ie. the value of the 10 variables "det[beam#]_freq1" to "det[beam#]_freq10" are greater than 2), the array variable named "moreRelatedLines" is set to 1. This variable is used to determine the outcome of the tactical decision following the task "Are There Other Related Lines?" A tactical decision following this task directs the line to "Check Database" if the line has not already been logged or to "Searc
29.20.5	Search Triple Beam Set	This task terminates if the line has already been logged. The variable named Op#Detect is set to 1 to enable the Operator to carry out the Basic Search process.
29.20.6	Check Database	The mean time is set to 60 with a standard deviation of 10 seconds.
29.20.7	Is Line From a Known Source?	The mean time is set to 10 with a standard deviation of 2 seconds. 70 percent of the time a probabilistic decision following this task routes the line to the task "Is There Other Evidence?" to indicate the signal is not generated by a known source. Alternatively, 30 percent of the time the line is directed to the task "Is Line Likely from TG?" to indicate the Operator determined the signal was likely generated by the Task Group.
29.20.9	Is There Other Evidence?	The task mean time is set to 720 with a standard deviation of 45 seconds. 50 percent of the time a probabilistic decision following this task directs lines to "ID Source" to indicate other evidence is found to identify the target. Alternatively, 50 percent of the time the line is directed to "ID Unknown" to indicate no evidence is found to enable the Operator to identify the target.
29.20.16	Is Line Likely from TG?	50 percent of the time a probabilistic decision following this task directs the tag to "Are There Related Lines?" to indicate the line is generated by an unknown source and not assocated with the Task Group. Alternatively, 50 percent of the time the decision directs the line to the task "Search Triple Beam Set" to indicate the line was likely generated by the Task Group.
29.20.17	Search Triple Beam Set	This task terminates because the line is likely from the Task Group The variable named Op#Detect is set to 1 to enable the Operator to carry out the Basic Search process.
29.20.8	Are There Other Related Lines?	A tactical decision following this task directs the line to either "ID Source" if there are no more related lines (ie. the value of the array variable named MoreRelatedLines is set to 0) or to "Search for Other Lines on Beam" if there are more related lines left to be found (ie. the value of the array variable named MoreRelatedLines is set to 1).

Task Event #	Task Title	Task Description
29.20.10	Search for Other Lines on Beam	The task mean time is set to 240 with a standard deviation of 75 seconds. A fixed link directs the line to "Are There Any Other Lines Found?"
29.20.11	Are Other Lines Found?	The task mean time is set to 0.5 seconds. 50 percent of the time a probabilistic decision following this task directs lines to the task "ID Source" to indicate all lines related to this contact have been found. Alternatively, 50 percent of the time the decision directs the line to the task "ID Poss" to indicate all lines related to this contact have not yet been found.
29.20.12	ID Unknown	The task mean time is set to 2 with a standard deviation of 0.4 seconds. The task terminates and increments the value of the variable named "ID_Unknown" by 1.
29.20.13	ID Poss	The task mean time is set to 2 with a standard deviation of 0.4 seconds. The task terminates and increments the value of the variable named "ID_Poss" by 1.
29.20.15	ID Source	The task mean time is set to 2 with a standard deviation of 0.4 seconds. The task terminates and increments the value of the variable named "ID_Source" by 1.
Log Process		
29.24	Log Contact	The task mean time is set to 35 with a standard deviation of 5 seconds. The value of the variable named "logged_lines" is incremented by 1 to count the total number of lines logged during the simulation.
29.25	Are There Other Lines on the Same Beam?	The task mean time is set to 0.5. The task terminates and the value of the variable Op#Detect is set to 1 to enable the Operator to return to the Basic Search process.
Scenario Events		
	OpBeam	Every 4 seconds, this repeating scenario event calls either the function named "OpBeam" if sanitizeMode is equal to 0 (ie. Array Sanitization complete) or the function named "SanitizeBeam" if sanitizeMode is equal to 1 (ie. Array Sanitization in progress). The OpBeam function moves both Operator1 and Operator2 to the next beam if there are no lines left to detect on the display or on the current triple beam set. Operator1 starts at beam 1 and moves up the array while Operator2 starts at beam 43 and moves down the array. The SanitizeBeam function only moves Operator1 while Operator2 is set to beam 0 because it is assumed Operator2 is occupied sanitizing the array.
	UpdateOps	Every second, this repeating scenario event calls a set of functions [i.e. UpdateOp1, UpdateOp2, UpdateOp1Tag, and UpdateOp2Tag] to update the current status of Operator1 and Operator2 in terms of the current triple beam set each Operator is examining, the number of lines on the current beam, and the number of lines the Operator is in process of examining.

Annex B: Description of the function parameters for each modelled task

B1. Functions that are unique to the Basic Search process (see Task Network 29).

Function Name and Number	**29.3 to 29.17 Examine triple beam set**			
Description	The operator searches the triple beam display for evidence of a sonar signal.			
Triggering Conditions	Standard surveillance -- select triple beam set (29.2). Continuous repeating task (29.3 to 29.17).			
End conditions/ consequences	If no evidence of sonar signal-operator continues examination of next triple beam set (29.3 to 29.17). If evidence of signal operator determines if sonar data is evidence of signal or noise (29.18).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Gamma	Function (4+#lines ^1.3)	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Discriminate: 3.7	NA	Signal Recognition: 3.7	Continuous Adjustive: 2.6

Function Name and Number	**29.18 Decision: is sonar data evidence of signal or statistical noise?**			
Description	The operator examines the characteristics of a single piece of sonar data to determine whether it is likely to come from a signal source or is random statistical noise.			
Triggering Conditions	Appearance on the display of any data that are higher contrast than the background. Standard surveillance (29.3 to 29.17).			
End conditions/ consequences	If noise – ignore noise and resume search for other sonar data (29.21). If signal – select single beam to analyse further (29.20).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Lognormal	10.0	3	.01
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	29.24 Log Data		NA	100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Discriminate: 3.7	NA	Signal Recognition: 3.7	Continuous Adjustive: 2.6

Function Name and Number	**29.20.1 Select single beam**			
Description	The operator selects a single beam mode to provide greater resolution of the sonar data			
Triggering Conditions	Operator detects sonar data of interest (29.18).			
End conditions/ consequences	The beam is selected and displayed and the operator goes on to analyse the sonar data to determine if the sound source is mechanical (29.20.2).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2.0	.4	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect: 1.0	NA	Automatic: 1.0	Discrete Actuation: 2.2

Function Name and Number	**29.20.2 Decision: is the source mechanical?**			
Description	The operator analyses the frequency and temporal characteristics of the sonar data and decides whether it is likely to be caused by a mechanical or non-mechanical agent. The operator may listen to the source to assist the analysis.			
Triggering Conditions	Operator detects sonar data of interest (29.20.1).			
End conditions/ consequences	The operator checks the log to see if the sonar data have been entered (29.20.3). NOTE: In reality, the Operator would reject any lines that were not generated by a mechanical source. For the purposes of this model, it is assumed all lines are mechanical.			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	5.0	0	0.001
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	29.24 Log Data		NA	100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Inspect/Check: 4.0	Discriminate Sound Characteristics: 6.6	Evaluation /Judgment: 4.6	Continuous Adjustive: 2.6

Function Name and Number	**29.20.3 Check log**			
Description	The operator searches the paper log to determine whether the line at this frequency has already been logged. As the log grows over time, this search becomes longer.			
Triggering Conditions	Operator determines whether or not sonar data as coming from a mechanical source (29.20.2).			
End conditions/ consequences	Operator decides whether or not the line is already logged (29.20.4).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Gamma	20.0	5	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	NA	Signal Recognition: 3.7	Continuous Adjustive: 2.6

Function Name and Number	**29.20.4 Decision: is the line logged?**			
Description	The operator either finds or fails to find an entry in the log. Once the log is found, the decision is virtually instantaneous.			
Triggering Conditions	Operator identifies sonar data and checks the log to determine whether the line at this frequency has already been logged (29.20.3).			
End conditions/ consequences	If the line is in the log already the operator resumes search on this triple beam set (29.20.5). If the line is not in the log, the operator enters the sonar data by manual entry and checks the database of known contacts (29.20.6).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	.5	.005	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	100%
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Alternative Selection: 1.2	NA

Function Name and Number	**29.20.6 Check database**			
Description	The operator searches for any other available information that may assist in identifying the source of this line – either from lists of known sources or from other forms of evidence (e.g. acoustics, reports).			
Triggering Conditions	The sonar datum is not found in the log (29.20.4)			
End conditions/ consequences	Operator checks to determine whether or not the line is from a known source (29.20.7)			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	60.0	10	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	Discriminate Sound Characteristics: 6.6	Evaluation /Judgment, Several: 6.80	Discrete Actuation: 2.2
Function Name and Number	**29.20.7 Decision: is line from known source?**			

Description	After searching sources operator decides whether there is evidence to identify the line as coming from a known source.			
Triggering Conditions	The sonar datum is not found in the log and the operator commences search for other evidence (29.20.6).			
End conditions/ consequences	If positive evidence- the operator decides that line is from a known source and the operator attempts to determine if line is likely from the Task Group (29.20.16). If no evidence- the operator seeks other evidence (29.20.9).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Gamma	10	2	0.001
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	29.24: Enter Log			100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Evaluation /Judgment, Several: 6.80	NA

Function Name and Number	**29.20.8 Are there other related lines?**			
Description	The operator checks the database to see whether this possible target has other lines which will need to be found to confirm the ID.			
Triggering Conditions	Operator finds evidence that potentially identifies source (29.20.15). The operator determines that the line is not from the Task Group (29.20.16).			
End conditions/ consequences	If there are other lines- operator searches for these lines (29.20.10). If there are no other lines-operator identifies source (29.20.15).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	0	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	NA	Signal Recognition: 3.7	Continuous Adjustive: 2.6

Function Name and Number	**29.20.9 Decision: is there other evidence?**			
Description	After searching databases of known sources operator decides whether there is any other evidence to identify the line.			
Triggering Conditions	The operator fails to find evidence of the source of the line from searching through available information on known sources (29.20.7).			
End conditions/ consequences	If positive evidence- the operator can proceed to identify source (29.20.15). If no evidence- the operator identifies the source as Unknown (29.20.12).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	720	45	0.001
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	29.20.15: ID Source			100
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	Discriminate sound characteristics: 6.6	Evaluation /Judgment, Several: 6.80	Continuous Adjustive: 2.6

Function Name and Number	**20.20.10 Search for other lines on beam**			
Description	The operator looks for expected lines at specific frequencies on the display.			
Triggering Conditions	The operator has found in the database information that this possible target has other lines. (20.20.8)			
End conditions/ consequences	If search finds lines, Operator determines if other lines are found (29.20.11). Search fails to find lines, Operator determines if other lines are found (29.20.11).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	240	75	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Inspect/Check: 4.0	NA	6.8 Evaluation Several Aspects	Continuous Adjustive: 2.6

Function Name and Number	**29.20.11 Decision: Are other lines found?**			
Description	The operator decides whether the display contains the expected lines.			
Triggering Conditions	The operator has found in the database information that this possible target has other lines (29.20.10).			
End conditions/ consequences	Search finds all related lines – source can be identified (29.20.15). Search fails to find all related lines- source can be ID as possible (29.20.13).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	.5	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Signal Recognition: 3.7	NA

Function Name and Number	**29.20.12 Identify source – Unknown**			
Description	The operator identifies the source			
Triggering Conditions	Operator fails to find any other evidence that would ID source (29.20.9).			
End conditions/ consequences	Operator logs the information (29.24)			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	.4	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Evaluation /Judgment, Several: 6.80	NA

Function Name and Number	**29.20.13 Identify source – Possible**			
Description	The operator identifies the source.			
Triggering Conditions	Operator finds fails to find other lines that would positively ID source (29.20.11).			
End conditions/ consequences	Operator logs the information (29.24).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	.4	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Evaluation /Judgment, Several: 6.80	NA

Function Name and Number	**29.20.15 Identify source**			
Description	The operator identifies the source.			
Triggering Conditions	Operator finds other lines that ID source (29.20.11). Operator finds no other lines to ID source (29.20.8). Operator finds positive evidence to ID source (29.20.9).			
End conditions/ consequences	Operator logs the information (29.24).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	1	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	50%
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Evaluation /Judgment, Several: 6.80	NA

Function Name and Number	**29.20.16 Decision: is line likely from TG?**			
Description	The operator determines if the line is from the Task Group.			
Triggering Conditions	Operator finds evidence that line is from a known source (29.20.7).			
End conditions/ consequences	If the line is from the Task Group, the operator resumes search on this triple beam set (29.20.17). If the line is not from the Task Group, the operator proceeds to determine if there are other related lines (29.20.8).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	0	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	NA	NA

Function Name and Number	**29.24 Log Contact**			
Description	The operator writes the information into the log (time will depend on number of lines found).			
Triggering Conditions	Contact is identified Unknown (29.20.12). Contact is identified Possible (29.20.13). Contact is identified (29.20.15).			
End conditions/ consequences	Operator searches for other lines on the same beam (29.25).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Gamma	35	5.0	.30
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	29.20.15 ID Source			50%
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	NA	Encoding/Decoding: 5.3	Symbolic Production: 6.5

B2: Functions that are unique to the Auto-Sanitise process (See Task Network 1).

Function Name and Number	**21 Display Data for Ownship/TG Database**			
Description	Operator actuates quick access button (QAB) to display data on known beam – this is done automatically by the system.			
Triggering Conditions	Beginning of watch and when part of regular sanitisation schedule of every 10 minutes.			
End conditions/ consequences	Data are displayed and Operator determines if pattern matches lines displayed (22).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA			
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	NA	NA

Function Name and Number	**22 Does pattern match lines displayed?**			
Description	Operator visually checks displayed template against actual lines on the display			
Triggering Conditions	First beam containing line is for the current Task Group member is displayed (21). Next beam containing line is for the current Task Group member is displayed (28).			
End conditions/ consequences	Operator decides whether the lines displayed match the template. If the pattern does not match, the Operator proceeds to Analyze Data (23). If the pattern matches the line displayed, the Operator proceeds to determine if All Beams are Accounted For (24).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	10 for 25 lines 40 for 100 lines	2	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Discriminate: 3.7	NA	Evaluation /Judgement (single): 4.6	Discrete Actuation: 2.2

Function Name and Number	**23 Analyse Data**			
Description	Operator conducts an analysis of the data based upon other information that may be available.			
Triggering Conditions	Template does not match lines displayed (22).			
End conditions/ consequences	Operator makes decision on whether lines are likely to be ownship/TG (25).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Gamma	60 for 25 Lines 240 for 100 Lines	12	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Locate/Align: 5.0	Discriminate Sound Characteristics: 6.6	Evaluation /Judgment (Several): 6.8	Continuous Adjustive: 2.6

Function Name and Number	**24 Are all beams accounted for?**			
Description	Operator looks at display to see if template pattern is displayed on other beams			
Triggering Conditions	Line pattern matches template (22). Analysis complete on current beam (27).			
End conditions/ consequences	If more data exists on other beams, operator iteratively repeats pattern matching/analysis process for other beams (22). If no more data is found on other beams, the operator proceeds to next TG member (26).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Inspect/Check: 4.0	Detect/Register Sound: 1.0	Evaluation /Judgement (Single): 4.6	Discrete Actuation: 2.2

Function Name and Number	**25 Are Displayed Lines from Ownship/TG?**			
Description	Based upon the prior analysis the operator decides on whether the lines are from ownship/TG or not.			
Triggering Conditions	Analysis of displayed lines completed (23).			
End conditions/ consequences	Operator decides source of lines is not attributed to Ownship/TG (27). Operator decides source of lines is attributed to Ownship/TG (28).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	Automatic: 1.0	NA

Function Name and Number	**26 Are all TG accounted for?**			
Description	Operator determines if santisation completed for all ownship/TG. Simple QAB continues process for next TG member.			
Triggering Conditions	All Beams are accounted for TG/Ownship (24). All Beams are accounted for and analysis complete on current ownship/TG (28).			
End conditions/ consequences	If completed operator resumes standard search/identification process (30). If not completed, operator iterates through remaining TG (15).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Inspect/Check: 4.0	NA	Evaluation /Judgement: 4.6	2.2 Discrete Actuation

Function Name and Number	**27 Update Database**			
Description	If the lines are from ownship/TG, the database is updated to reflect the current data. This process would be accomplished through clicking on lines, QAB action and menu selection.			
Triggering Conditions	Lines are identified as from Ownship/TG (25).			
End conditions/ consequences	Database is updated to reflect current data (24).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	30 for 25 Lines 120 for 100 Lines	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	NA	Automatic: 1.0	Symbolic Production: 6.5

Function Name and Number	**28 Display Data for Ownship/TG**			
Description	Operator enters updated information into database			
Triggering Conditions	Operator decides source of lines is attributed to Ownship/TG (28).			
End conditions/ consequences	More Beams have yet to be examined for the current Task Group member. The next beam containing line is for the current Task Group member is displayed (22). All Beams are accounted for and analysis complete on current Ownship/TG (26).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	0	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	NA	NA	NA	NA

B3. Functions that are unique to the Manual Sanitise process (see Task Network 1).

Function Name and Number	**9 Select Beam**			
Description	Operator selects the next beam to examine.			
Triggering Conditions	Operator selects next beam to search for the current Task Group member (Task 4 to 8).			
End conditions/ consequences	Operator searches beam (10).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect: 1.0	NA	Alternative Selection: 1.2	Discrete Actuation: 2.2

Function Name and Number	**10 Search Beam for All Lines**			
Description	Operator searches the current beam for all TG/Ownship lines.			
Triggering Conditions	Operator selects the next beam for the current Task Group member (9).			
End conditions/ consequences	Operator logs all possible contacts on the current beam (11).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect: 1.0	NA	Automatic: 1.0	NA

Function Name and Number	**11 Found All Lines?**			
Description	Operator searches beam for all lines.			
Triggering Conditions	Operator searches beam (10).			
End conditions/ consequences	Log lines found on beam (11).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect: 1.0	NA	Automatic 1.0	NA

Function Name and Number	**12 Log Lines**			
Description	Log is updated to reflect the current data. This process is completed manually.			
Triggering Conditions	All lines are found on the current beam (11).			
End conditions/ consequences	The Operator determines whether there are more beams to search for the current Task Group member (13).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	30 for 25 Lines 60 for 100 Lines	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Read: 5.9	NA	Automatic: 1.0	Symbolic Production: 6.5

Function Name and Number	**13 More Beams to Search?**			
Description	Operator determines whether or not all beams have been searched.			
Triggering Conditions	All lines are logged on the current beam (12).			
End conditions/ consequences	If more remaining beams exist for the current Task Group member, the Operator selects the next beam (9). If there are no more remaining beams to search for the current Task Group member, the Operator determines if all Task Group members have been identified (14).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect: 1.0	NA	Automatic: 1.0	Discrete Actuation: 2.2

Function Name and Number	**14 All TG Done?**			
Description	Operator determines whether or not all Task Group members have been identified.			
Triggering Conditions				
End conditions/ consequences	When all Task Group members have been identified, the Operator continues with the Basic Search process (30). If more Task Group members remain to be identified, the Operator selects the next Task Group member (3).			
Properties	Distribution	Mean Time (sec)	Std. Deviation	Prob of failure
	Normal	2	0	0
Consequences of failure	Task affected		Percent Time Degradation	Percent Failure Degradation
	NA		NA	NA
Workload Rating	Visual	Auditory	Cognitive	Psychomotor
	Register/Detect 1.0	NA	Automatic 1.0	Discrete Actuation 2.2

B4. Functions that are common between the Automated and Manual Sanitise Process (see Task Network 1).

<table>
<tr><td>Function Name and Number</td><td colspan="4">2. Manual or Auto</td></tr>
<tr><td>Description</td><td colspan="4">This task is performed by the operator at the start of the watch</td></tr>
<tr><td>Triggering Conditions</td><td colspan="4">Start of simulation (1).
Watch handover is set to occur at the start of the simulation and every 600 seconds after the array has been sanitized (18).</td></tr>
<tr><td>End conditions/ consequences</td><td colspan="4">Operator makes a decision to manually (3) or automatically (15) sanitise the array.</td></tr>
<tr><td rowspan="2">Properties</td><td>Distribution</td><td>Mean Time (sec)</td><td>Std. Deviation</td><td>Prob of failure</td></tr>
<tr><td>Normal</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Consequences of failure</td><td colspan="2">Task affected</td><td>Percent Time Degradation</td><td>Percent Failure Degradation</td></tr>
<tr><td colspan="2">NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="2">Workload Rating</td><td>Visual</td><td>Auditory</td><td>Cognitive</td><td>Psychomotor</td></tr>
<tr><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

Annex C: Values selected for the Environmental Model

Values that are different from the default model are shown with a gray background.

Variable	Acceptable Values	Units	Value	Default Initial Value
Physical				
Ambient_Noise	0 to 200	dBA	75	3
Contamination_Level	None, High, Medium, Low	NoneHiMedLow	None	None
Contamination_Type	None, Biological, Nuclear, Chemical	Contamination_Type	None	None
Digability	NA, Very_Hard, Moderately_Hard, Firm, Soft, Very_Soft	Digability	NA	NA
Dry_Bulb_Temperature	-100 to +100	Degrees_Celsius	20	30
Env_Type	Air, Water	EnvType	Air	Air
Footing	NA, Black_Top, Dirt_Road, Light_Brush, Packed_Snow, Heavy_Brush, Swampy_Bog, Loose_Sand, Soft_Snow	Footing_Type	NA	NA
Humidity	0 to 100	Percent	20	20
Illumination	Noon_Day, Summer_Sunlight, Average_Clear_Day, Average_Overcast_Day, Dusk, Moonlight, Starlight, Redlighting	Illum_Type	dusk	Noon_ Day
Pressure	0-10,000,000	Pascals	101,325	101,325
Sea_State	None, Slight, Moderate, Severe	Motion	Moderate	None
Temperature	-100 to +100	Degrees_Celsius	15	100
Terrain	None, Rock, Forest, Desert	Terrain_Type	None	None
Terrain_Direction	0 to <360	Degrees	0	0
Terrain_Slope	-90 to 90	Degrees	0	0
Thermal_Radiation	0-10,000,000	Watts/m^2	0	0
Time_Of_Day	0 to 2400	Hours	600	600
Turbulence	None, Slight, Moderate, Severe	Motion	None	None
Weather	Clear, Heavy_Rain, Medium_Rain, Heavy_Snow, Medium_Snow, Mist, Fog, Heavy_Overcast,	Wx_Type	Clear	Clear

Variable	Acceptable Values	Units	Value	Default Initial Value
	Medium_Overcast			
Wind_Direction	0 to 360	Degrees	0	0
Wind_Speed	0 to 500	Metres/sec	0	0
Wind_Strength	0 to 12	Beaufort	0	2
Mission				
Adequacy_Of_Procedures	NA, Good, Moderate, Poor	GoodModPoor	Good	Good
Communications_Density	High, Medium, Low	HiMedLow	Medium	Medium
Intelligence	Good, Moderate, Incomplete, None	Intelligence	Good	Good
Platform_Reliability	0 to 100	Percent	95	95
Surveillance_Reliability	0 to 100	Percent	75	75
Time_Stress	0 to 100	Percent	50	0
Weapons_Reliability	0 to 100	Percent	75	75
Crew				
Clarity_of_Role	Good, Average, Poor	GoodAvgPoor	Good	Good
Cooperation	NA, Good, Moderate, Poor	GoodModPoor	Good	Good
Leadership_Style	NA, Good, Moderate, Poor	GoodModPoor	Good	Good
Supervision	Yes, No	Yes/No	Yes	Yes
Team_Experience	0 to 50	Years	1	1
Team_Morale	None, High, Medium, Low	NoneHiMedLow	Medium	Medium
Team_Training	None, High, Medium, Low	NoneHiMedLow	Medium	Medium
Threat				
Target_Bearing	0 to 360	Degrees	0	0
Target_Elevation	0 to 50,000	Metres	0	0
Target_Location	NA, Land, Air, Sea	Location	Sea	NA
Target_Obscuration	Visible, Partially_Visible, Invisible	Obscuration	Partially_Visible	Visible
Target_Range	0 to 100	Kilometres	25	0
Threat_Severity	None, High, Medium, Low	NoneHiMedLow	High	None
Target_Signature	None, High, Medium, Low	NoneHiMedLow	Low	None
Target_Speed	0 to 2,000	Metres/sec	3	0
Target_Value	None, High, Medium, Low	NoneHiMedLow	High	None

Annex D. The Crew Model

Trait Variables	Acceptable Values	Units	Value	Default Initial Value
Agility	None, High, Medium, Low	NoneHiMedLow	Medium	Medium
Auditory_Acuity	0 to 100	dB	40	0
Cognitive_Ability	None, High, Medium, Low	NoneHiMedLow	Med	Low
Fitness	0 to 500	Watts	250	250
Mental_Capacity	0 to 100	Percent	75	50
Motion_Sickness	None, High, Medium, Low	NoneHiMedLow	None	None
Personality	Non_Neurotic_Introvert, Neurotic_Introvert, Non_Neurotic_Extrovert, Neurotic_Extrovert	Personality	Non_Neurotic_Extrovert	Non_Neurotic_Extrovert
Physical_Skill_Level	None, High, Medium, Low	None	Medium	Medium
Time_Since_Training	0 to 48	Months	6	6
Visual_Acuity	1 to 10	None	10	5
Years_in_Position	0 to 50	Years	2	2
State Variables	**Acceptable Values**	**Units**	**Value**	**Default Initial Value**
Auditory_Signal_Localisation	0 to 3600	Mils	0	0
Clothing	0 to 100	Clo's	10	10
Comfort	None, High, Medium, Low	NoneHiMedLow	Medium	Medium
Confidence_in_System	High, Medium, Low	HiMedLow	High	Low
Encumbrance	None, High, Medium, Low	NoneHiMedLow	None	Low
Fear	None, High, Medium, Low	NoneHiMedLow	Low	None
Field_of_View	0 to 3200	Mils	600	600
Hunger	None, High, Medium, Low	NoneHiMedLow	Low	Low

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14. ABSTRACT

(U) This is a demonstration project to illustrate the benefits of task network modelling as a means of quantifying future changes to system design or operational concepts prior to the build stage or system implementation. The specific task environment selected for the demonstration is the process of analysing narrow band sonar data to detect and identify sonar targets, which are key tasks in building the Underwater Maritime Picture. Function and critical task analysis of existing sonar analysis practices were conducted to generate appropriate functions and tasks to be modelled. The Integrated Performance Modelling Environment (IPME) software was used to build a task network model, the essential components of which were validated by an experienced Navy sonar subject matter expert. The model was then used to assess the effects of semi-automating the critical process of sanitising ownship and Task Group sonar data from the display, by comparing system performance for baseline (manual) and automated conditions. Results showed a performance increase for the automated of approximately 30% in terms of contacts identified. This performance gain was achieved with no costs to operator workload. The prototype system developed provides core functionality to explore future “what-if” questions with respect to the redesign of sonar systems and their concept of operations.

(U) Il s'agit d'un projet de démonstration qui vise à montrer les avantages de la modélisation d'un réseau de tâches comme moyen de quantifier les futurs changements à apporter à la conception de systèmes ou à leurs concepts opérationnels avant la construction ou la mise en œuvre des systèmes. Ce qu'on a retenu comme conditions d'exécution des tâches particulières aux fins de la démonstration, c'est le processus d'analyse des données obtenues par sonar à bande étroite pour la détection et l'identification des cibles sonar, qui regroupe des tâches-clés de l'établissement de la situation maritime sous-marine. L'analyse de tâches critiques et de fonctions a été appliquée aux pratiques d'analyse de données sonar en place pour générer les tâches et les fonctions appropriées à modéliser. Le logiciel d'environnement intégré de modélisation de la performance (IPME) a été utilisé pour la mise au point d'un modèle de réseau de tâches, dont les éléments essentiels ont été validés par un expert chevronné du sonar de la Marine. Le modèle a ensuite servi à l'évaluation des effets de la semi-automatisation du processus critique d'épuration des données sonar de son propre navire et du groupe opérationnel de l'affichage, par une comparaison du rendement des systèmes entre un modèle de référence (manuel) et des conditions automatisées. Les résultats ont fait ressortir, dans le cas des conditions automatisées, une amélioration du rendement d'environ 30 % en ce qui concerne les contacts identifiés. Ce gain de rendement a été réalisé sans accroissement de la charge de travail de l'opérateur. Le prototype élaboré assure les fonctions de base pour explorer les futures questions hypothétiques en ce qui concerne le remaniement des systèmes sonar et leur concept d'opération.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) sonar systems; automation; human performance; simulation and modelling; target detection; sanitization

Trait Variables	Acceptable Values	Units	Value	Default Initial Value
Manual_Dexterity	High, Medium, Low	HiMedLow	Medium	Medium
Mental_Alertness	High, Medium, Low	HiMedLow	Medium	Medium
Morale	High, Medium, Low	HiMedLow	Medium	Medium
Motivation	High, Medium, Low	HiMedLow	Medium	Medium
NBC_Kit	None, Nuclear, Chemical, Biological	Contamination_Type	None	Biological
Perceived_Safety	None, High, Medium, Low	NoneHiMedLow	Medium	Medium
Perceived_Target_Value	None, High, Medium, Low	NoneHiMedLow	Hi	None
Perceived_Threat	None, High, Medium, Low	NoneHiMedLow	High	None
Physical_Fatigue	0 to 10	None	5	5
Physical_Load	0 to 100	Kilograms	0	0
Psychological_Stress	None, High, Medium, Low	NoneHiMedLow	Med	Low
Situation_Awareness	Good, Average, Poor	GoodAvgPoor	Average	Average
Thermal_Stress	0 to 100	Degrees_Celsius	15	30
Thirst	None, High, Medium, Low	NoneHiMedLow	Low	Low
Time_Since_Ate	0 to 100	Hours	6	2
Time_Since_Drank	0 to 100	Hours	3	4
Time_Since_Slept	0 to 100	Hours	7	4